FINAL REPORT

AN EVALUATION OF THE EFFECT OF LEVEL OF SERVICE AND COST ON DEMAND FOR INTERCITY BUS TRAVEL

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies)

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ABSTRACT

This report describes an evaluation of the effect on intercity bus ridership of changes in frequency of service and cost. The study was based on a comparison of travel between 19 selected cities in Virginia served by air, bus, or rail. These modes were compared with highway travel by auto using various assumptions of energy availability. The effect of increasing the frequency of bus service was also investigated to determine if it is a viable means for attracting additional travel demands.

Network data for each mode consisted of travel time, cost, and frequency of service. These data were applied to three state of-the-art intercity travel demand models selected from eleven reported in the literature. A status quo demand estimate was produced for travel within the Virginia system and the results were compared with demand resulting from increasing the number of bus departures per day and increasing per mile auto costs. The effect of increases in bus fare due to rising fuel costs was also determined.

The results of this investigation indicate that intercity bus travel demand will not be significantly altered with increases in the number of bus departures per day, but will increase as costs of auto fuel rise. The intercity demand model developed by the state of Michigan yielded the most consistent results of all models tested.

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INTRODUCTION

Nationwide, the intercity bus industry consists of approximately 276,000 miles (442,000 km) of regular routes serving approximately 15,000 communities, 93% of which are not served by any other mode of public transportation. In Virginia, service is provided by 12 bus companies covering an estimated 300 principal communities, the majority of which are served by only the bus.

Since 1966, the intercity bus industry has experienced a 20.0% decline in regular route miles and a 5.5% decline in total route miles.(1) Between 1971 and 1976, operating expenses increased from $664.4 million to $945.5 million, an increase of 30.5%. This increase corresponds to a decrease in the operating profit margin from 12.4% to 4.5%. In the same time span, revenue passengers decreased 5.2%, even though charter and special service increased 82.6% from 1971 to 1977.(2)

The Wisconsin Department of Transportation, in its study entitled Intercity Bus Transportation in Wisconsin, reported that between 1970 and 1975 total route miles on the Wisconsin bus network declined 11%, operating expenses increased 69%, the operating profit margin decreased 4.7%, and annual ridership decreased 26%.(3)

There are several reasons for the decline in regular route and total route miles of intercity transportation in the United States. Among these are (1) development of the interstate highway network, (2) an increase in charter service, and (3) the elimination of marginal or unprofitable routes. Technological advances developed by competing common carriers (primarily air) have lowered both cost per passenger mile and city to city travel time, and the result has been a substantial growth in those competitive markets. Subsidies are not available to the intercity bus industry. On the other hand, airlines do receive aid, which assists in maintaining unprofitable service, and Amtrak, the national passenger rail system, is subsidized for operating losses and capital outlays to purchase new equipment and facilities.

Thus, with a declining share of the market and a lack of government subsidy, the intercity bus industry faces a crisis of rising costs and declining passengers and revenue. The industry has found it increasingly difficult to replace obsolete equipment and facilities. Revenue can no longer be increased simply by raising fares because of competition from other common carriers and the private automobile. The viability of the bus industry will depend on the competitive advantage created by improvements in level of service and external factors that will affect the relative cost of each mode. The effects of these changes on bus patronage is the topic of this report.

PURPOSE AND SCOPE

The purpose of this study was to investigate the service characteristics of the intercity bus industry in Virginia, to examine and evaluate state-of-the-art intercity travel demand forecasting models, to select and implement appropriate intercity travel models using the Virginia bus network, and to determine the likely effect on intercity bus patronage of changes in bus service supply (frequency of service) and increases in the price of fuel.

Data on passenger travel was unobtainable in this study and travel demand forecasting was restricted to models reported in the literature. No attempt was made to calibrate a forecasting model using origin-destination data of intercity bus travelers in Virginia. The use of previously calibrated models was considered to be appropriate in this situation as the study was concerned with the relative importance of various service and socioeconomic factors and the resulting changes in ridership. The study results are not dependent on absolute values of ridership between city pairs.

The models are sensitive to conditions that affect the intercity bus markets, including level of service characteristics (e.g. travel time, cost, and frequency of service), socioeconomic variables (e.g. population and income), and the availability of competing modes (e.g. air, rail, and auto). The models were applied to selected routes within the state and analyzed for consistency and trends.

METHODOLOGY

The study involved four basic tasks: (1) a review of the known characteristics of intercity bus users; (2) investigation of intercity demand models and selection of models appropriate to Virginia conditions; (3) the selection of a network of routes and collection of data on system characteristics, and (4) network investigation and evaluation. Each of these tasks is described below.

Intercity Bus User Characteristics

Three sources were used to obtain information about the intercity bus user and travel demand forecasting. These were: (1) a file search performed through the facilities of the Highway Research Information Service, (2) an examination of the publications of the Transportation Research Board on travel demand forecasting, and (3) contacts with specific state departments of transportation where intercity bus studies or intercity demand studies had been performed.

Investigation of Intercity Demand Models

From the collection of studies reviewed, eleven models were identified and investigated for applicability to the Virginia intercity bus network. Data requirements were categorized for each model and this performance was investigated. From the collection of models obtained, those most adaptive to the Virginia network were selected for implementation.

Route Selection and Data Collection

Typical routes throughout the state were selected for use in a network investigation. Data concerning level of intercity travel service required for each model were obtained by consulting the Official Airline Guide, Russell's Official National Motor Coach Guide, and highway maps, and by contacting common carriers. Socioeconomic variables were found in the 1970 census and other state publications. The data are based on conditions as of 1978.

Network Investigation and Evaluation

The models selected were implemented through the use of the computing facilities at the Virginia Highway and Transportation Research Council.

The network was investigated by applying the models using various level of service scenarios. The results produced were used to describe how the intercity bus market flucuates in response to various levels of service as provided by the intercity bus carriers and is affected by the service of competing modes of travel.

The results obtained from each of the models were evaluated to determine if they reasonably portrayed the actual characteristics of the Virginia intercity bus market. Each model was evaluated for its overall performance in describing intercity bus travel using a Virginia data base.

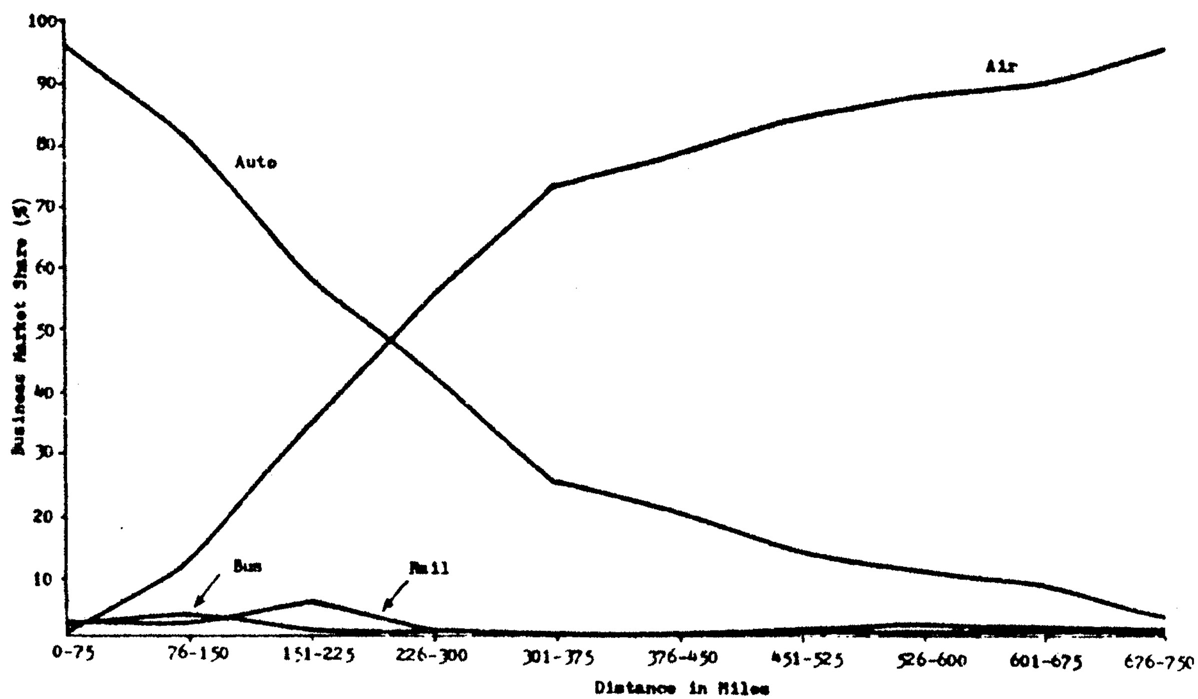
CHARACTERISTICS OF INTERCITY BUS USERS

The purpose of this section is to briefly review current information on intercity bus transportation characteristics. The data reported are based on comprehensive, intercity statewide bus studies completed in Iowa, Michigan, Oregon, Tennessee, and Wisconsin. Other sources were the Interstate Commerce Commission (ICC) and the American Bus Association (ABA).

Modal Comparison

Intercity buses carry more people than any other public transportation mode. In 1976, intercity buses carried 340 million passengers compared to 220 million airline passengers and 18 million rail passengers.[4] The intercity bus system directly reaches more communities than does any other common carrier and the system contains more route miles than any of the other public transportation modes.

Figures 1 and 2 show relative market shares for auto, air, bus, and rail as a function of travel distance and trip purpose. For both business or nonbusiness travel, the proportionate share by air increases as trip length increases. Air travel attracts passengers from the automobile market faster than from other common carrier markets. For travel distances in excess of about 250 (400 km) miles, the market share retained by intercity bus declines rapidly.



Source: Cohen, G.S., Enlbaum, N.S., Hartgen, D.T., "Intercity Rail Patronage in the NYC-Buffalo Corridor; Models and Forecasts", Preliminary Research Report 115, New York State Department of Transportation, Albany, N.Y., May 1977.

Figure 1. Business mode split.

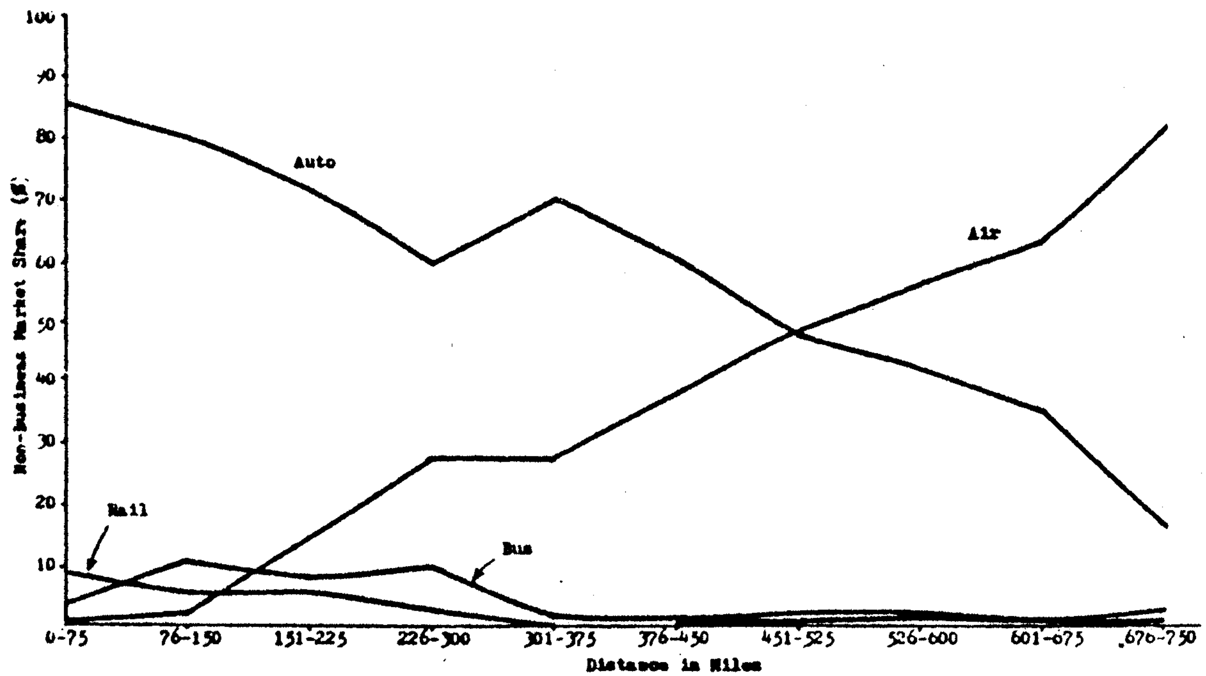


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Figure 2. Nonbusiness mode split.

Bus User Profiles

Intercity bus users consist of both captive and choice riders. Generally, captive riders are persons who do not have ready access to an automobile for making the trip. This group includes many elderly, handicapped, and young people, and those with limited financial resources. Choice riders are those who have a choice in selecting a transportation mode for making the trip. Riders who choose to travel by bus do so because of reduced cost, energy conservation, safety, or the overall perceived benefit of traveling by intercity bus.(5)

User Occupation

The occupations of bus users, as reported in several statewide surveys, are shown in Table 1. Three occupational groups appear to be the predominant users of intercity bus transportation. Students represent over 20% of all passengers. The next highest category is made up of professional and technical employees, and these are followed by retirees. Professional and technical employees account for approximately 17% of the riders, and retirees account for about 15% of the total.

User Income, Age and Sex

The income of intercity bus riders as reported in four studies is shown in Table 2. Approximately 40% of bus riders earn less than $10,000 per year, and 20% earn less than $5,000. Approximately 15% of riders earn $20,000 or more.

Table 3 shows that a substantial percentage of riders (approximately 30%) are between the ages of 18 and 24 years. However, a substantial portion are under 18. Retired persons were previously shown to be a significant user group. Over 10% of bus users are 65 years and over. The age group with the lowest percentage of users is the range of 35-55 years.

Six intercity bus studies provide information on user sex. The results, shown in Table 4, indicate that the predominant user is female, and accounts for between 55% and 70% of riders.

User Trip Purpose

One of the most useful classifications of intercity bus travel is trip purpose. Five of the studies reviewed gave some indication of the purposes of trips and these are shown in Table 5.

Table 1

Ridership Percentage by Occupation

Occupation	Iowa	Michigan	Tennessee	Wisconsin	ICC
Professional/technical	19	11	32	18	15.0
Craftsman		10	15[a]	2	10.6[a]
Labor				5	
Service		3	5	3	5.9
Office/Clerical		4	14	7	11.7
Homemaker		13			
Student	24	29		31	
Unemployed		7		5	
Retired	17	12	33[b]	12	15.8
Other		9		9	17.1

[a]Craftsman and Labor

[b]Retired and other

Table 2

Ridership Percentage By Income

Michigan		Iowa		Wisconsin		ICC	
$0 - 2,999	13	less than $5,000	25.8	$0-4,999	18.3	$0 - 4,999	26.5
$3,000-5,999	13	less than $10,000	47.2	$5,000-9,999	16.8	$5,000-7,499	17.4
$6,000-8,999	11	less than $20,000	15.1	$10,000-14,999	12.6	$7,500-9,999	14.9
$9,000-11,999	9			$15,000-19,999	10.5	$10,000-14,999	23.4
$12,000-14,999	10			$20,000-24,999	6.5	$15,000 over	13.4
$15,000-14,999	8			$25,000 over	8.8		
$25,000 over	11						

Table 3

Ridership Percentage by Age

Michigan		Oregon		Wisconsin		ICC	
17 or under	6	under 16	13	under 18	14.1	under 18	30.0
18-29	46	16-44	51	18-24	32.0	18-24	7.9
30-39	11	45-64	20	25-34	13.2	25-34	10.9
40-49	9	65 and over	16	35-44	6.5	35-44	8.4
50-64	15			45-54	7.5	45-54	10.8
65 and over	11			65 and over	10.2	65 and over	16.8

Table 4

Ridership Percentage by Sex

Sex	Michigan	Iowa	Oregon	Wisconsin	ABA	ICC
Male	41		34	31.7		36.9
Female	55	70.9	65	61.8	61	59.5
No Response	40			5.5		3.1

Table 5

Ridership Percentage by Trip Purpose

Trip Purpose	Michigan	Iowa	Oregon	ABA	ICC
work	14		7		
shop	1		1		
conduct business			10		12.2
personal business	16			88	
visit friends/relatives	47	50.1			32.6
social activity			48		
vacation/recreation	6		13		7.0
other social recreation	2				30.7
other	11		12		17.5

*personal and family matters

The primary trip purpose is to visit friends or relatives. Over 45% of the users fall into this category. The ABA report indicates that 88% of the users' trips were for personal and family matters. The percentage of trips for work was small and that for shopping was almost insignificant. Thus, a majority of the trips appear to have been for social or recreational reasons.

Availability of Another Mode

To obtain a clear understanding of the division between captive and choice riders, a review was made of three of the previously mentioned intercity bus studies that provided information on the extent of dependency on the bus.[3,5,6]

The Iowa study indicated that over 66% of the riders were dependent on the bus to make their trip. This category could include those with access to a competing common carrier. The Iowa study also found that approximately 40% of the riders did not have access to a family car.

The Oregon study showed that only 17% of the riders had no access to an automobile and only 1% of the riders had only the choice of the intercity bus. Thus, it appears that there was a substantial proportion of choice riders in Oregon.

The Wisconsin study had a similar finding to that of the Iowa study; approximately 46% of the riders were dependent on the bus to make their trip. This may indicate that in Wisconsin, too, there was a substantial portion of choice riders traveling by intercity bus.

Summary

A profile of the average bus user can be described based on characteristics provided from intercity bus studies. The typical intercity bus rider is a female student under the age of 25 years, with an annual income less than $10,000. She would be traveling for social reasons and would most likely be visiting friends or relatives. Her trip would be less than 250 miles (400 km) in length and would last no more than six hours.

Other riders on the bus would be professionally or technically employed or retired. Very few people on the bus would be middle-aged. Most of the bus riders would be traveling for social reasons.

INTERCITY TRAVEL DEMAND MODELS

In order to make comparisons of the effects of service and cost changes on intercity bus travel demand it is necessary to determine the ridership on each competing mode (e.g. auto, rail, and air) under a specified set of system characteristics. This study identified eleven travel demand models that have been used for intercity forecasting. This section examines the characteristics of these models, the socioeconomic and system variables used, their data requirements, and their outputs.

Model Characteristics and Classification

Characteristics of each model are shown in Table 6 in terms of the model output, input, modes considered, and adjustment factors. For example, the Baumol-Quant model (to be described later) produces travel demand by air, auto, bus, and rail based on socioeconomic variables of population, median income, and city characteristics, and system characteristics of number of modes, travel time, cost, and frequency of service.

Intercity travel demand models are classified as pre-distribution, post-distribution and hybrid. Discussions of these types follow.

Pre-distribution Models

Pre-distribution models forecast mode-specific demand directly through a comparison of modal attributes or through time series forecasts of base year volumes. A generalized format of a pre-distribution model is

Modal demand = (production function) x (impedance function).

The trip production function usually consists of socioeconomic terms such as population and economic variables. The impedance expression includes system characteristics such as travel time, cost and frequency of service. Figure 3 illustrates the relationship of the two generalized input expressions to the model output.

Pre-distribution models are useful in explaining captive ridership. The models tend to rely on the production function to produce modal travel by selecting an appropriate measure of population such as the percentage of government employees in the origin and destination cities. The impedance expression identifies the mode being investigated. The process generally produces results which are insensitive to the attributes of competing modes. Total travel demand is found by summing all modal demands.

Table 6

Model Characteristics

Intercity Demand Study	Model Output	Modes Considered	Model Inputs: Socioeconomic	Model Inputs: System	Adjustment Factors
Barmol-Quandt	Modal travel	air auto bus rail	- population - median income - institutional characteristic	- number of modes - travel time - cost - frequency of service	
Kraft-Sarc	Modal travel	air auto bus rail	- population - mean income	- travel time - cost - frequency of service	
Sacremento-San Francisco	Modal travel	singular mode	-extensive production and attraction (community data) -intensive production and attraction (household data)	- auto speed - auto cost - travel time - walking and waiting time - frequency of service - terminals - path	
Transport Canada	Modal travel	air auto bus rail	- population - linguistics index	- travel time - cost - frequency of service	- city-pair mode specific
Intercity Transportation Effectiveness	Air travel	air	- population	- nonstop travel time - expected travel time - access and egress time - frequency of service	- time trend - mode trip probability - attraction

Table 6 (cont'd)

Model Characteristics

Intercity Demand Study	Model Output	Modes Considered	Model Inputs: Socioeconomic	Model Inputs: System	Adjustment Factors
Canadian Transportation Commission	Modal travel	air auto bus rail	- population - linguistics index - % families with income greater than $12,000	- highway driving time - avg total trip time by common carrier - travel time - cost - frequency of service	
Michigan	Modal travel	air auto bus rail	- families with income greater than $10,000	- travel time - out of pocket cost - frequency of service	
Spaith	Modal travel	air auto bus rail	- population - per capita income	- door to door travel time - avg travel time - door to door cost - avg. cost - frequency of service - distance	
NECTP	Modal split	air auto bus rail		- travel time - cost - frequency of service	
NYSDOT	Modal travel	air auto bus rail	- population - % government employed	- travel time - avg non business travel time - cost - frequency of service - distance	- normalization - pivot point
West Virginia	Total travel		- population	- travel time	

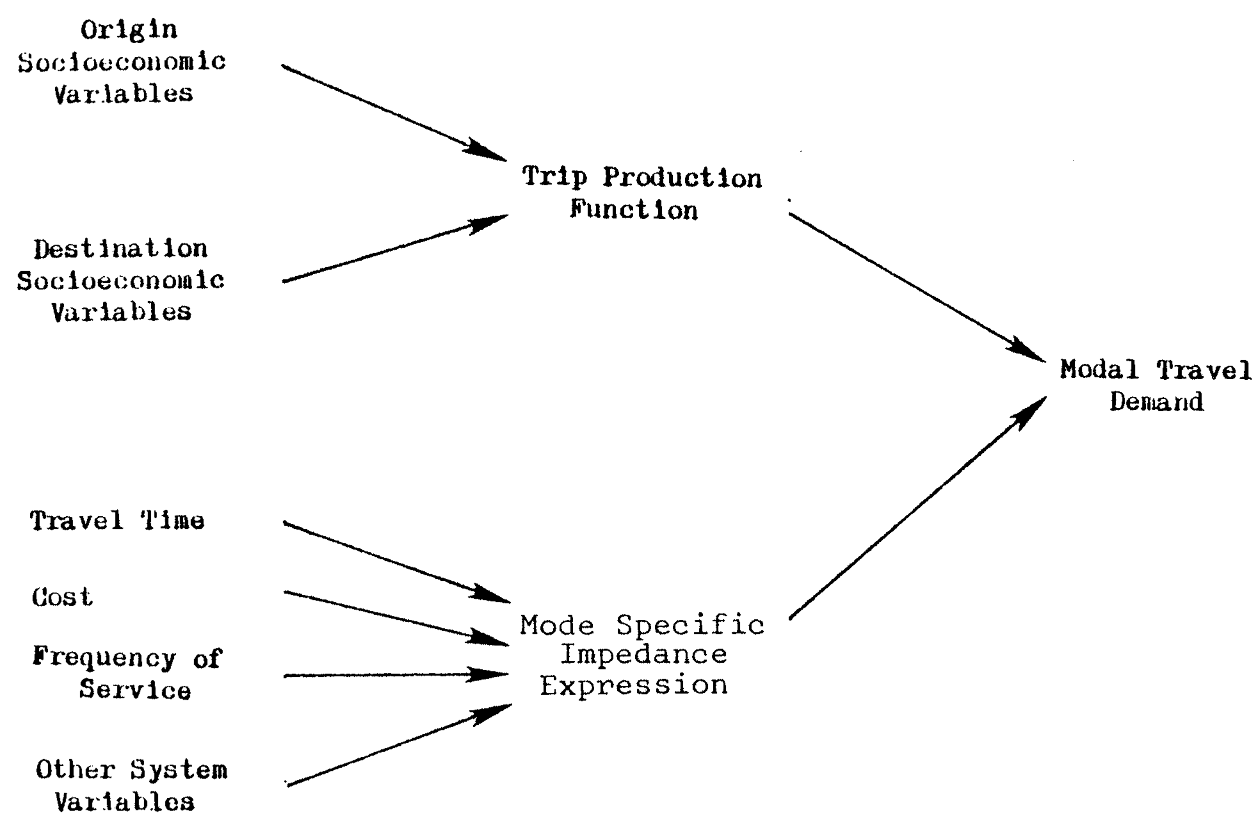

Figure 3. Pre-distribution model diagram.

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Post-distribution Models

Post-distribution models forecast mode-specific travel demand through a forecast of total travel and modal split or market share. The total travel portion of a post-distribution model is unlike the trip production function of a pre-distribution model in that it is a forecast of the total travel by all modes between a specific origin-destination city pair. The total travel forecast then distributed among competing modes through the modal split forecast portion of the model. A generalized format of a post-distribution model is

Model demand = (total travel) x (modal split).

The total travel expression is commonly a simple or modified gravity model which employs socioeconomic measures of the origin and destination cities. The modal split forecast utilizes a comparison of a mode's level of service to the total level of service of all modes combined. A mode's level of service is defined by system variables such as travel time, cost and frequency of service. Figure 4 illustrates the components of the two sections of the model and how they relate to the model output.

Post-distribution models are especially useful in explaining the effects of competing modes. Hence, they are useful in explaining the behavior of choice riders. One weakness is apparent with the model form. Post-distribution models suffer from the so-called Independence of Irrelevant Alternatives (IIA) axiom, which has the property that new traffic attracted to an alternative mode will be drawn from the other alternative modes in proportion to their original share. Latent demand is not accounted for in the model structure. This can lead to absurd diversions in certain market contexts.(7)

Hybrid Models

Hybrid models combine the strengths of the pre- and post-distribution model approaches. The total travel portion of the post-distribution model can be combined in a number of methods with the modal demand results of the pre-distribution models to balance the total modal demands. Such procedures often require a comprehensive data base and may require complicated calibration techniques.

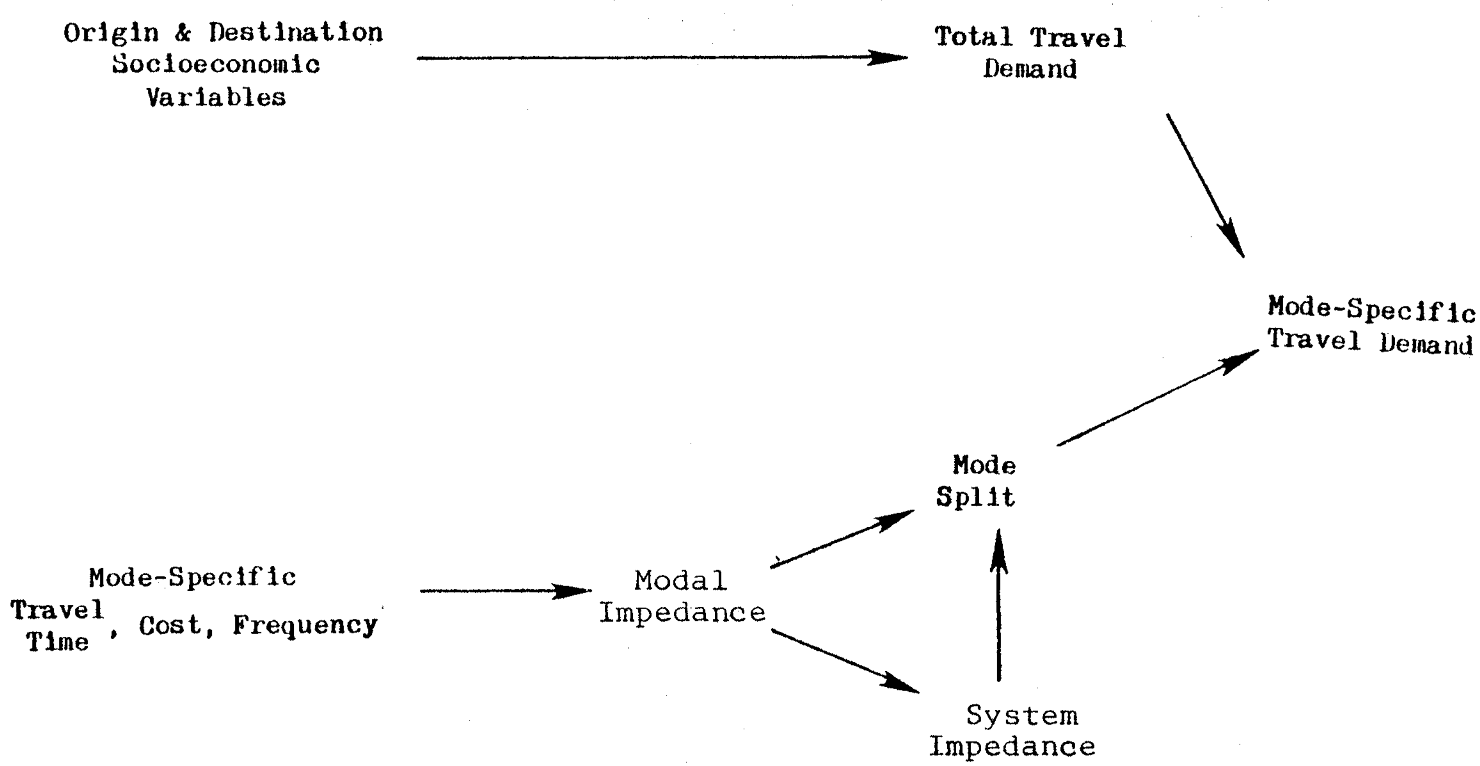

Figure 4. Post-distribution model diagram.

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MODEL REVIEW

This section contains a description of the 11 intercity travel demand models as classified in the previous section. Five of the models are pre-distribution and six are post-distribution models. This section furnishes a discussion of each of these models in order to determine their possible use in the Virginia study.

Pre-distribution Models

Pre-distribution models have been in use longer than any other form of travel demand models. Two classical models are presented first, the Baumol-Quandt abstract mode model and the Kraft-Sarc demand model. Following these two models are descriptions of travel demand models developed for the Sacramento-San Francisco corridor, for Canadian travel demand, and for forecasting air travel demand.

Baumol-Quandt

The Baumol-Quandt abstract mode model became widely used subsequent to its application in the Northeast Corrodor Project.(7) The model is unique in its ability to accommodate an abstract mode. An abstract mode is a hypothetical mode which may have corresponding characteristics that are better than currently available modes. An example would be vertical take-off and landing (VTOL) or short take-off and landing (STOC) air transportation service.

Figure 5 illustrates in general terms the relationship of the trip production function and its terms associated with the travel impedance expression and the parameters it comprises. The mode for which travel demand is being forecast is identified in the relative level of service parameters. The characteristic of the mode is compared to the characteristic of the best mode.

Model Formulation

$$T_{kij} = a_o P_i^{k_1} \; P_j^{k_2} \; Y_i^{k_3} \; Y_j^{k_3} \; M_i^{k_5} \; M_j^{k_6} \; N_{ij}^{k_7} \; f_1(H) f_2(C) f_3(D)$$

$$f_1 = (H_{ij}^{\;b})^{k_1} (H_{kij}^{\;r})^{k_2}$$

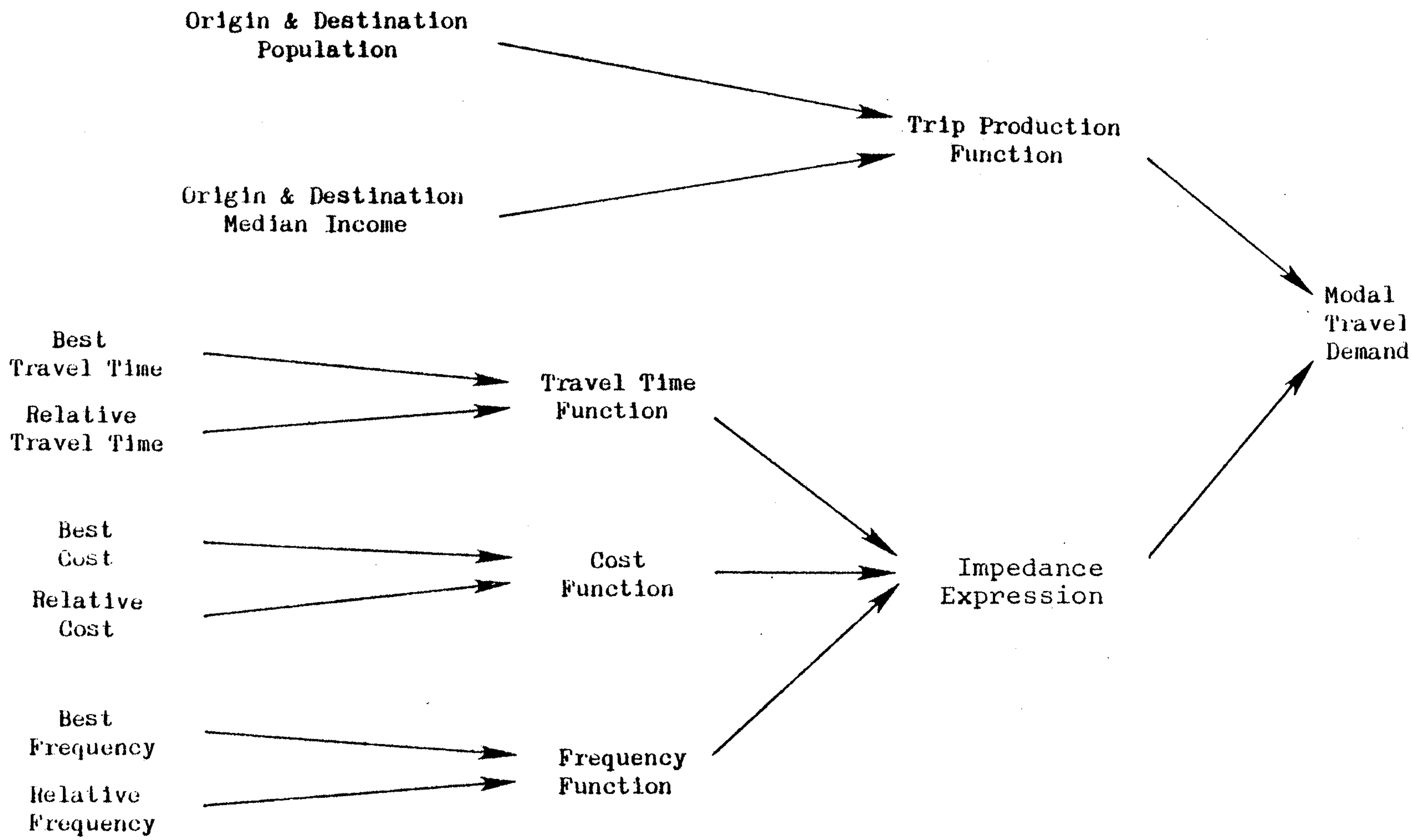

Figure 5. Baumal-Quandt abstract mode model.

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$$f_2 = (C_{ij}^{b})^{k_3}(C_{kij}^{r})^{k_4}$$

$$f_3 = (D_{ij}^{6})^{k_5}(D_{kij}^{r})^{k_6},$$

where

T_{kij} = travel by mode k between cities i and j,

P_i, P_j = population of cities i and j,

Y_i, Y_j = median income for cities i and j,

M_i, M_j = institutional character index for cities i and j,

N_{ij} = the number of modes serving cities i and j,

H_{kij} = travel time of the kth mode,

C_{kij} = cost of the kth mode,

D_{kij} = frequency of the kth mode, and

$k_i, \ldots, k_7$ = calibration coefficients.

A superscript b denotes the "best" value of the characteristic among all modes and the superscript r denotes the ratio of the value of the characteristic for the given mode to the value of the characteristic for the best mode.

Discussion

The elasticities of demand with respect to each variable are the calibration coefficients. The structure of the model indicates that the calibration coefficients are invariant. Hence, the model is said to be a constant elasticity model. This feature neglects how each mode competes with each other. An improvement in the non-best mode has little effect on the output of the model. The model does explain the competition between an individual mode and the best mode only in terms of each measure of the level of service.

Since the intercity bus usually provides more departures per day than any other common carrier, frequency of bus service can be considered as a best characteristic among all modes. Air and auto modes have the best characteristics of travel time and cost. In most intercity market contexts, intercity bus competes with only the private auto, which would have the best characteristics of travel time and cost.

Kraft-Sarc

The Kraft-Sarc intercity travel demand model was developed for the Northeast Corridor Project.[7] The model cannot accommodate an abstract mode in the same sense as the previous model. Level of service characteristics of an abstract mode can be applied with the model but the effect of it on competing modes is not shown as explicitly as with the Baumal-Quandt model.

Figure 6 illustrates in broad terms the components of the trip production function and the impedance expression. The mode being investigated is identified through the calibration coefficients. This will be discussed once the model formulation is presented.

Model Formulation

$$T_{kij} = a_o (P_i P_j)^{a_1} (IN_i, IN_j)^{a_2} \sum_{l=1}^{m} (Time_{ijl})^{a_3} (Cost_{ijl})^{a_4} (Freq_{ijl})^{a_5},$$

where

T_{kij} = trips made by mode k between i and j,

$P_i P_j$ = the product of the population of i and j,

IN_i, IN_j = the product of the mean income of i and j,

$Time_{ijl}$ = travel time by mode l between i and j,

$Cost_{ijl}$ = cost by mode l between i and j,

$Freq_{ijl}$ = frequency of service by mode l between i and j,

m = number of modes, and

$a_o, \ldots, a_5$ = calibration coefficients.

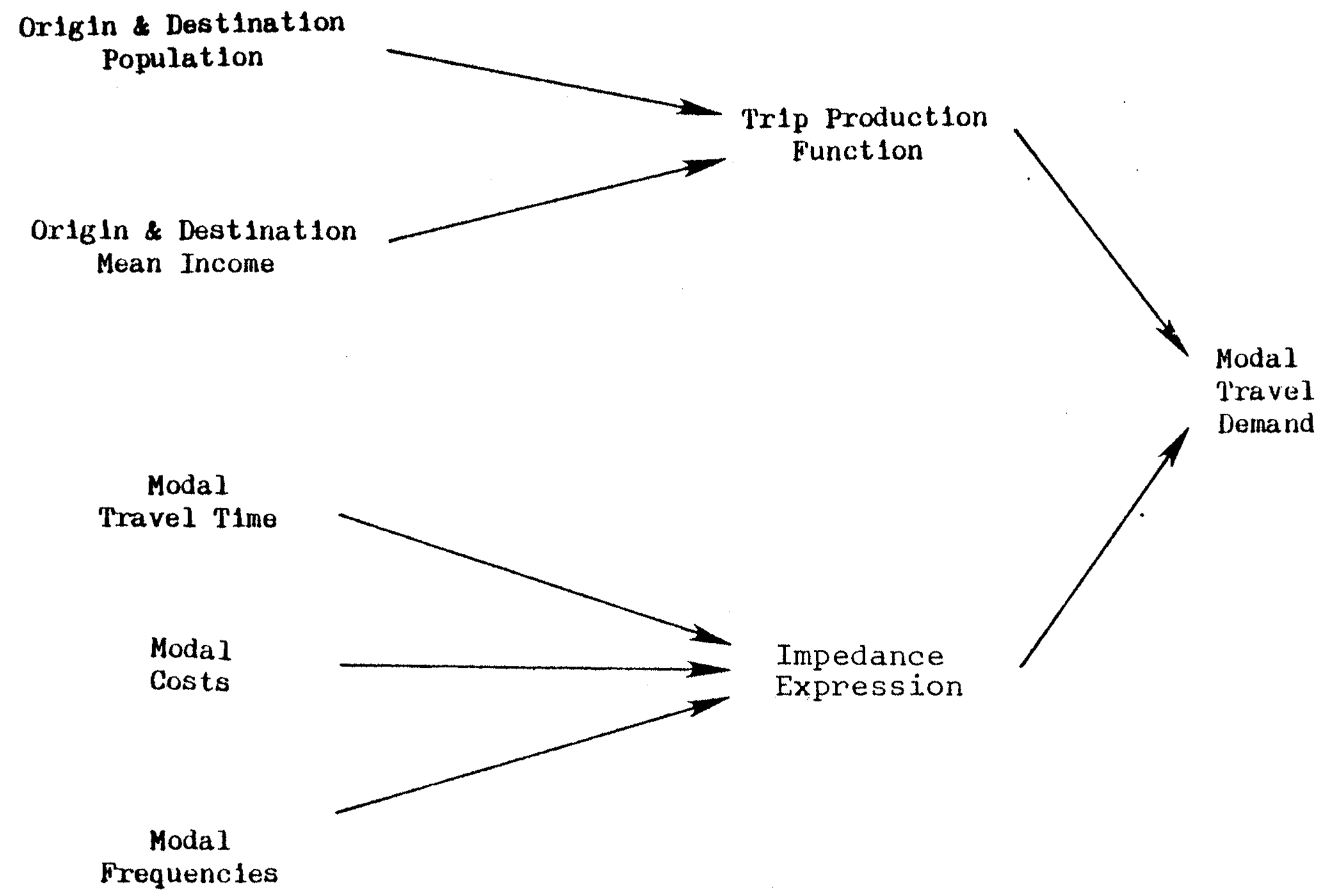

Figure 6. Kraft-Sarc travel demand model.

Discussion

The model is a constant elasticity model, with the elasticity with respect to each variable being the calibration coefficients. The mode being evaluated is identified through the calibration coefficients. Separate calibrations are performed for each mode. This is a standard feature of most pre-distribution models.

The model is more sensitive to competitive effects than the Baumal-Quandt model, since modal attributes (travel time, cost, and frequency of service) are assembled in a product form. This feature of the model provides ease in investigating and evaluating potential system changes. When investigating intercity bus passenger demand, the constant elasticity feature of the model combined with the product form of the level of service parameters results in an inadequate portrait of modal competition.

Though the model lends itself to examining system changes, it will not easily depict the diversion of passengers from other modes to a specific mode. Changes in system variables will provide an indication of the amount of induced travel. Thus, the model has some usefulness in explaining the competitive effects of all common carriers against the use of the private auto.

Sacramento-San Francisco

The model is an extension of the Baumal-Quandt abstract mode model.(7) It was developed for the Sacramento-Stockton-San Francisco corridor study. The model is structured to accommodate a broad range of system characteristics, fluctuations in gasoline prices, and other conditions surrounding transportation.

Figure 7 illustrates how the model can accommodate a broad range of variables and how the variables comprise the trip production function and the impedance expression. The theory of the model is based on the premise that a city will attract a certain number of trips due to characteristics of the city. At the same time, the city will produce a certain number of trips to another city because of another set of characteristics. The combination of production and attraction trips will lead to a measure of the total number of trips made between two cities. The total number of trips are impeded by the level of service and adjusted through adjustment factors.

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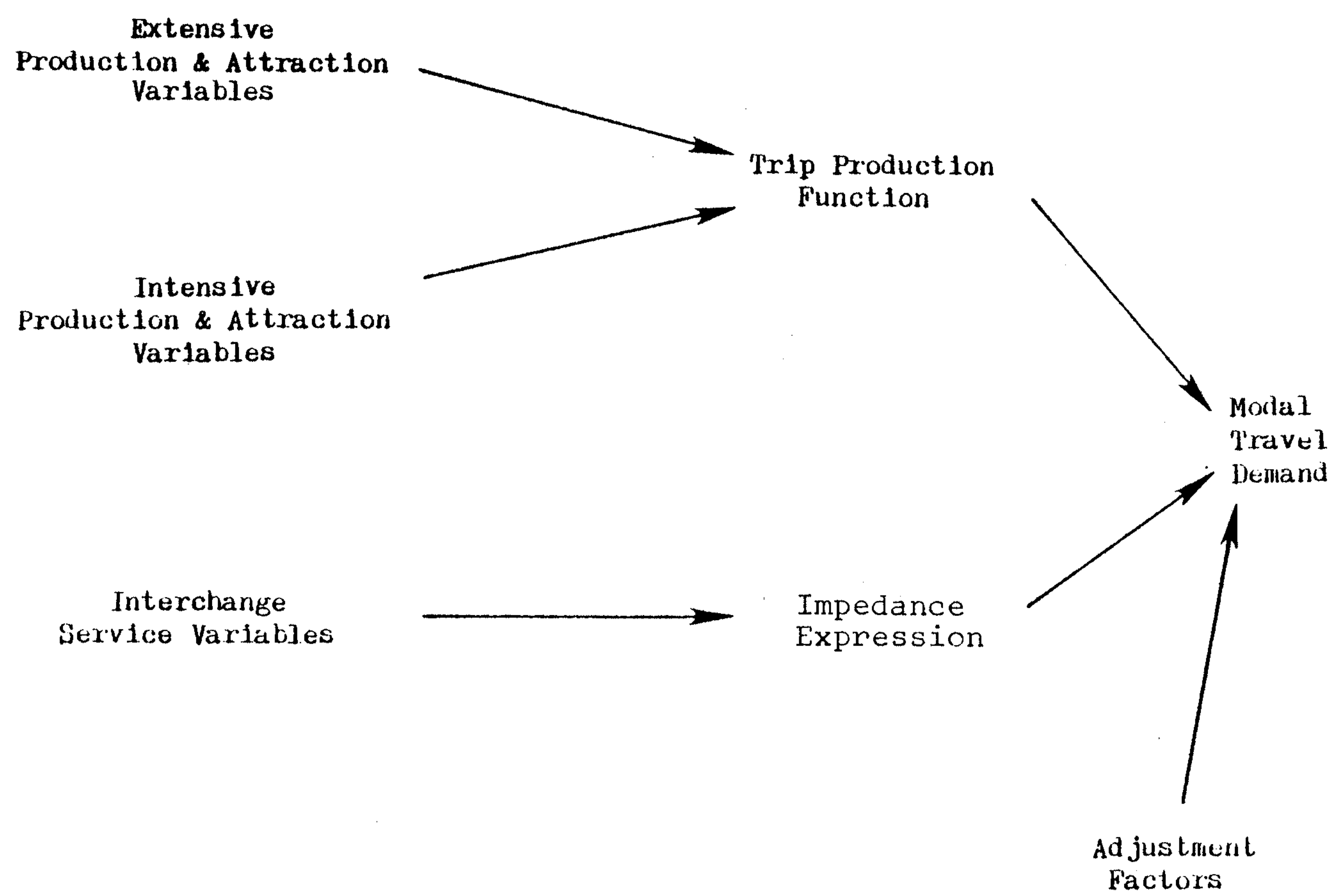

Figure 7. Sacramento-San Francisco corridor model.

Model Formulation

$$T = (\alpha_1 P_1 + \alpha_2 P_2)(\Pi_1 A_1 + \Pi_2 A_2) Z_1^a Z_2^b X_1^c X_2^d e^{f_1 g_1} e^{f_2 g_2},$$

where

T = trips between 1 & 2,

P_1, P_2, A_1, A_2 = extensive production and attraction variables,

Z_1, Z_2 = intensive production and attraction variables,

X_1, X_2 = interchange service variables, and

α = calibration coefficients.

The model was developed for two forecasts: the number of auto trips and the number of transit trips.

Discussion

The model represents an application of direct demand theory to the urban transportation case rather than to intercity transportation as it forecasts only auto and transit trips, without distinction between air, rail, and bus.

The model does not examine modal competition beyond the division of auto and transit trips. Nevertheless, it could be useful for estimating the demand of intercity markets where there is only one common carrier, as is often the case.

If there were more than one common carrier in an intercity market, it would be difficult to examine common carrier competition. For the model to be applicable in this situation, additional modal disaggregation would be required, which could weaken the structural integrity of the model.

Transport Canada

The Transport Canada model was developed to analyze the 1975 intercity air, auto, bus, and rail system throughout Canada.(8) Its form is similar to that of both the Baumal-Quandt and the Kraft-Sarc models. Abstract modes can be accommodated and modal competition is mathematically expressed.

Figure 8 identifies the components of the model. Two parameters in the model deserve additional comment. First, a linguistics pairing index is incorporated to account for cultural differences that may affect intercity travel. Second, a mode-specific adjustment factor is used to reduce residual error.

Model Formulation

$$T_{ijm} = (\exp a_o)P_{ij}^{a_1} \; L_{ij}^{a_2} \times (\sum_m C_{ijm}^{b_1} \; H_{ijm}^{b_2} \; D_{ijm}^{b_3})^{b_4}$$

$$\times (\exp k_m)(C_{ijm}^{b_1} \; H_{ijm}^{b_2} \; D_{ijm}^{b_3})/\sum_m (\exp k_m)$$

$$\times (C_{ijm}^{b_1} \; H_{ijm}^{b_2} \; D_{ijm}^{b_3}) \times F_{ijm},$$

where

T_{ijm} = travel demand ,city i to j on mode m;

P_{ij} = population cross product, cities i and j;

L_{ij} = linguistics pairing index, cities i and j;

C_{ijm} = cost or fare (cents) of mode m from city i to j;

H_{ijm} = travel time of mode m from city i to j;

D_{ijm} = departure frequency (per week) of mode m from city i to j;

k_m = modal constants that may be interpreted as modal acceptability factors representing the unmeasured convenience involved in intercity travel; and

F_{ijm} = city-pair modal-specific adjustment factor.

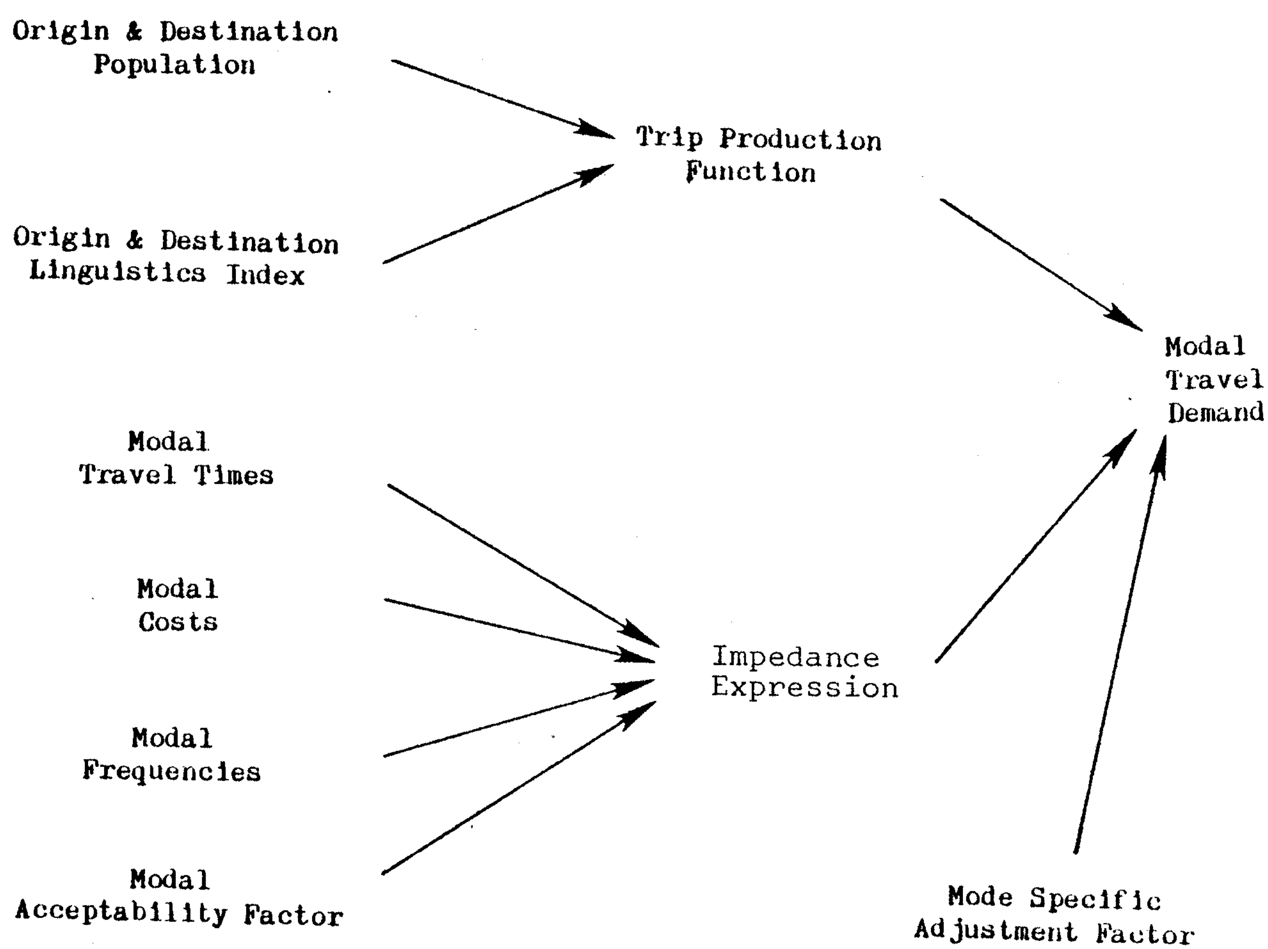

Figure 8. Transport Canada model.

Discussion

The numerous policy alternatives investigated (52 in all) ranged from the null alternative to combinations of changes affecting travel times (55 mph [88 km/h] highway speed limit combined with improving rail travel time) or costs (increases in the price of crude oil). The various scenarios were used to examine impacts on each individual mode.

The results of these various system changes showed that the intercity bus competes mainly with the auto, whereas changes in the air system produced only minor variation in intercity bus passenger demand. Surprisingly, modifications in the rail system produced little impact on intercity bus passenger demand.

Limiting the maximum speed limit to 55 mph (88 km/h) produced significant increases in intercity bus passenger demand, as did an increase in the price of crude oil and gasoline.

Intercity Transportation Effectiveness

The model was developed for the Department of Transportation to approximate intercity air passenger demand at major hub airports.(9) It is based on gravity model theory, as is each of the models previously described.

Figure 9 depicts the components of the model. It is the only time trend model reviewed. The time trend adjustment factor explains the growth pattern in air travel. The mode split adjustment factor accounts for differences in air travel attraction for short trips. The attraction adjustment factors depict the characteristics of the trip ends.

Model Formulation

$$V_{ij} = (P_i P_j)^a \times C_{ij} \times PF_{ij} \times S \times kF_{ij} \times kF_i \times kF_j$$

$$C_{ij} = \exp\,(g/(TF_{ij}T_i) + b/M_{ij} + d/W_{ij} + h/(A_i + A_j) + k),$$

where

V_{ij} = passenger demand for air trip from i to j;

P_i, P_j = population of i and j;

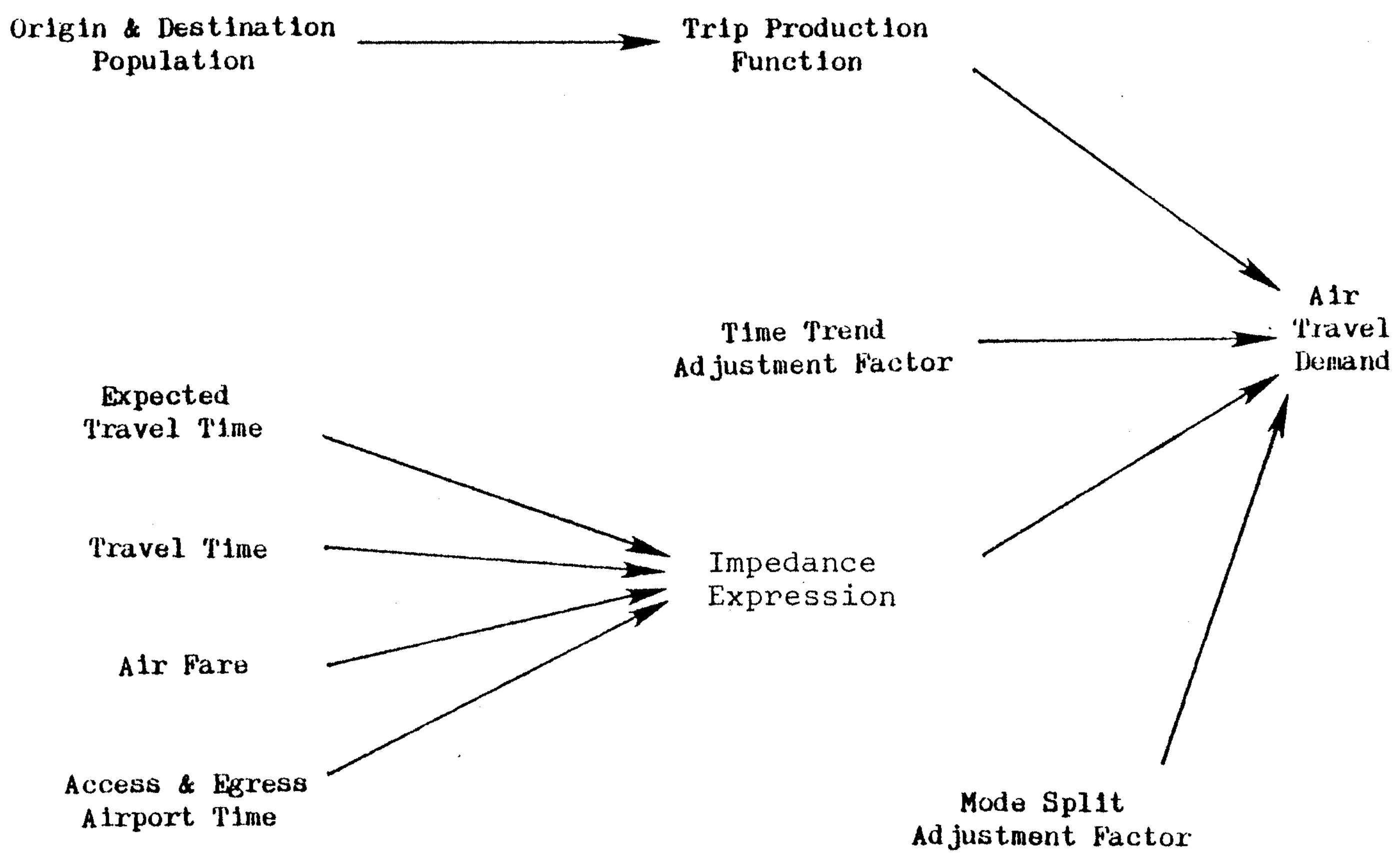

Figure 9. Intercity transportation effectiveness model.

C_{ij} = conductance function for trips between i and j;

PF_{ij} = air trip probability factor;

S = time trend adjustment factor;

kF_{ij}, kF_i, kF_j = adjustments for unusual level of attractiveness of travel between i and j, to/from i, to/from j;

T_{ij} = terminal-to-terminal nonstop travel time between i and j;

M_{ij} = terminal-to-terminal coach class air fare;

W_{ij} = frequency of service from i to j in flights per day;

A_i = access time to airport;

A_j = egress time from airport; and

a,b,d,g,h,k = calibration coefficients.

Discussion

The model has limited applicability for investigating intercity bus passenger demand. It does not consider modal competition. The review of this model was intended solely to provide insight into an additional approach to modeling intercity travel demand.

Post-distribution Models

The introduction of post-distribution models began almost a decade after the Baumol-Quandt model was implemented. These models are sensitive to competition between modes and thus useful for forecasting bus travel demand by choice riders. The models are characterized by two components: a total travel forecast and a modal split or market share prediction which distributes the total travel over the competing modes.

Of the five models classified as post-distribution models, four forecast modal travel demand and one estimates market shares. The unique feature of a post-distribution model is that the two components of the model are usually mutually exclusive. Thus, modal split forecasts can be compared without considering total travel predictions.

Canadian Transportation Commission

The intercity travel demand model used by the Canadian Transportation Commission was developed to study intercity passenger transportation in eastern Canada.(10) It is intended for use in investigating common carrier passenger demand. The model is formulated in such a way that the automobile passenger volumes are not required for its calibration.

Figure 10 illustrates the components of the total travel pattern of the model. Competition between common carriers and the automobile is accounted for by utilizing the difference between travel times and costs. As with the Transport Canada pre-distribution model, a linguistics pairing index is employed.

Model Formulation

$$w_i = k_i(T_i)^{b_1}(C_i)^{b_2}e^{(b_a/F_i)}$$

$$W = \sum_i w_i$$

$$S_i = w_i/W$$

$$V_{AB} = k(P_aP_B)^{a_1}(L_{AB})^{a_2}\exp\,(a_3/r_a)\exp\,(a_4[D-T])(C-\bar{P})^{a_5}W^{a_6},$$

where

w_i = impedance of mode i,

W = system impedance,

S_i = market share of mode i,

T_i = average total trip time by mode i,

C_i = average total cost by mode i,

F_i = daily departure frequency,

V_{AB} = annual total trips generated from city A to B by common carrier,

P_A, P_B = population of cities A and B,

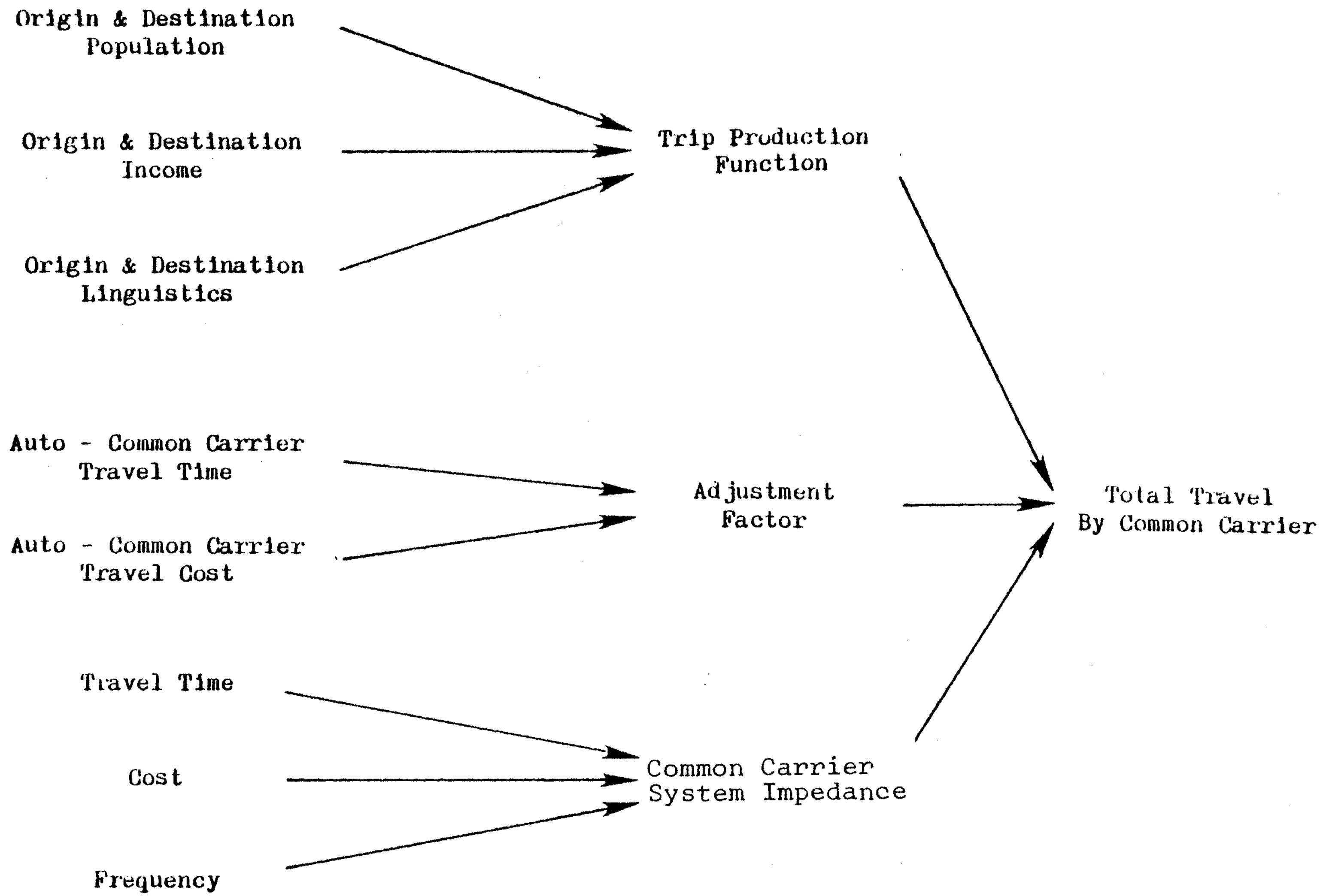

Figure 10. Canadian Transportation Commission model.

L_{AB} = linguistics pairing index,

r_A = % of families with income greater than $12,000,

D = highway driving time,

T = average total trip time by common carriers,

C = average total cost by common carriers,

P = perceived cost by automobile, and

$a_1,\ldots,a_6,b_1,b_2,b_3,k_i,k_t$ = calibration parameters.

The value of the linguistics pairing index equals zero when linguistic similarity does not exist and one when the city pair is linguistically matched. Mode-specific passenger demand is found through the product of the market share of the mode and the total common carrier demand.

Discussion

The model has been relatively successful in describing historical trends in the eastern Canada intercity transportation market. Use of the linguistics pairing index feature of the model would limit its applicability to Virginia conditions.

The model is capable of limited evaluation of abstract modes. Two such modes, the tracked air-cushion vehicle and STOL modes, were investigated. Such an evaluation is difficult and the results obtained must be viewed with skepticism since passenger levels, which are needed for effective model calibration, are estimated. Little was mentioned in the report pertaining to intercity bus passenger demand.

Northeast Corridor Transportation Project (NECTP)

The model presented here is the mode split model used extensively in the Northeast Corridor Transportation Project of the Department of Transportation.[11] The model has also received extensive use in other high density corridors in the United States. It was calibrated under seven conditions. The calibrated models are known as CN22 through CN28. CN27 is the best overall model and is stratified by trip purposes. CN22 is the best unstratified model.

Figure 11 describes the mode split model and can be used to describe most mode split models. Automobile passenger levels are required for calibration of the model. The model can easily be coupled with total travel models.

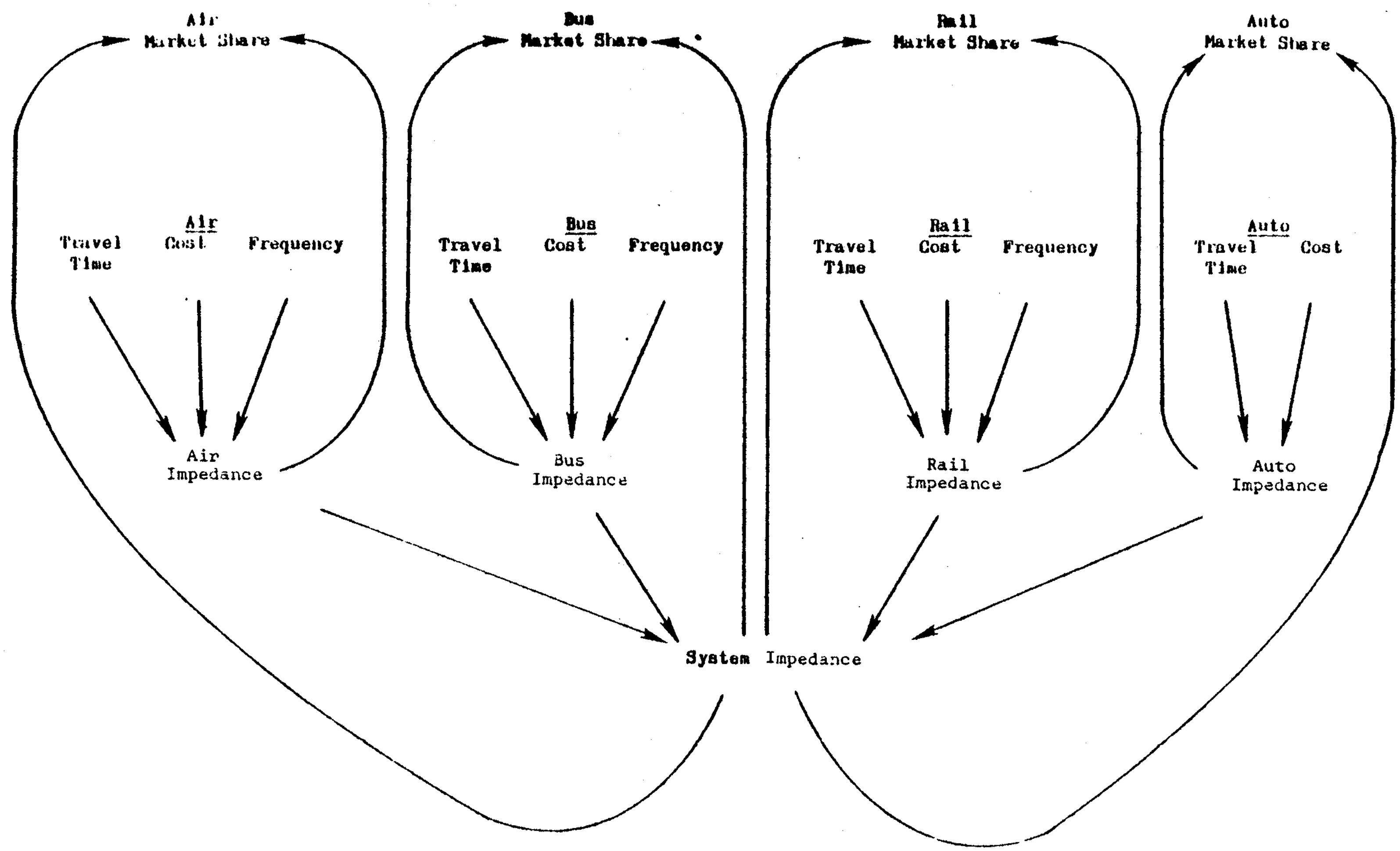

Figure 11. Northeast corridor mode split model.

Model Formulation

$$w_i = c_i \; t_i^{a_1} \; c_i^{a_2} \; f_i^{a_3}$$

$$f_i = (1 - \exp (- kf_i)$$

$$W = \Sigma_i w_i$$

$$S_i = \frac{w_i}{W} ,$$

where

w_i = impedance of mode i,

W = system impedance,

t_i = average one-way door-to-door travel time,

c_i = average one-way travel cost,

f_i = average number of one-way departures, and

C_i, k_i, a_1, a_2, a_3 = calibration coefficients.

Discussion

The model is a cross-elasticity model. The calibration coefficients a_1 and a_2 are negative since an increase in travel time or cost implies that a mode has become less attractive. The calibration coefficient a_3 will be positive since an increase in the frequency of service increases the personal utility derived by travel on that mode.

The model is easily adaptive to investigating intercity bus passenger demand. Historically, CN26 is the best model for determining intercity bus market share with non-Northeast Corridor data. However, for accurate results the model should be recalibrated if transferred.

Spaith

The intercity travel demand model developed by Spaith was developed using 150 city pairs obtained through the 1972 National

Travel Survey.[7] The model utilizes a modified gravity model to forecast total travel and NECTP model CN22 to forecast mode split.

Figure 12 illustrates the total travel portion of the model. Mode split is not shown since this is calculated using the NECTP model. The unique characteristic of this model is that the results of the mode split model are used in the forecast of total variables. As modal attributes change, the modal split adjusts to produce a new average travel time and cost across all modes.

Model Formulation

$$T_{ij} = b_o\left(P_iP_j\right)^{b_1}\left(Y_iY_j\right)^{b_2}\left(\frac{AC_{ij}}{d_{ij}}\right)^{b_3}\left(AT_{ij}\right)^{b_4},$$

where

T_{ij} = total travel between city i and city j,

P_i,P_j = population of cities i and j,

Y_i,Y_j = per capita income of cities i and j,

d_{ij} = distance between i and j,

AC_{ij} = system average travel cost between i and j,

AT_{ij} = system average travel time between i and j, and

$b_o,\ldots,b_4$ = calibration coefficients.

Discussion

The total travel model developed by Spaith is quite similar to the structure of pre-distribution models. The difference comes in the treatment of system variables. There isn't a calculation of impedance in the total travel portion of the model.

In most post-distribution models the total travel and mode split portions are mutually exclusive. This is not true in this model. This feature aids in accounting for latent demand since a change in the transportation system directly affects the total travel forecast. In some instances, the lack of accounting for latent demand is sighted as a weakness of post-distribution models.

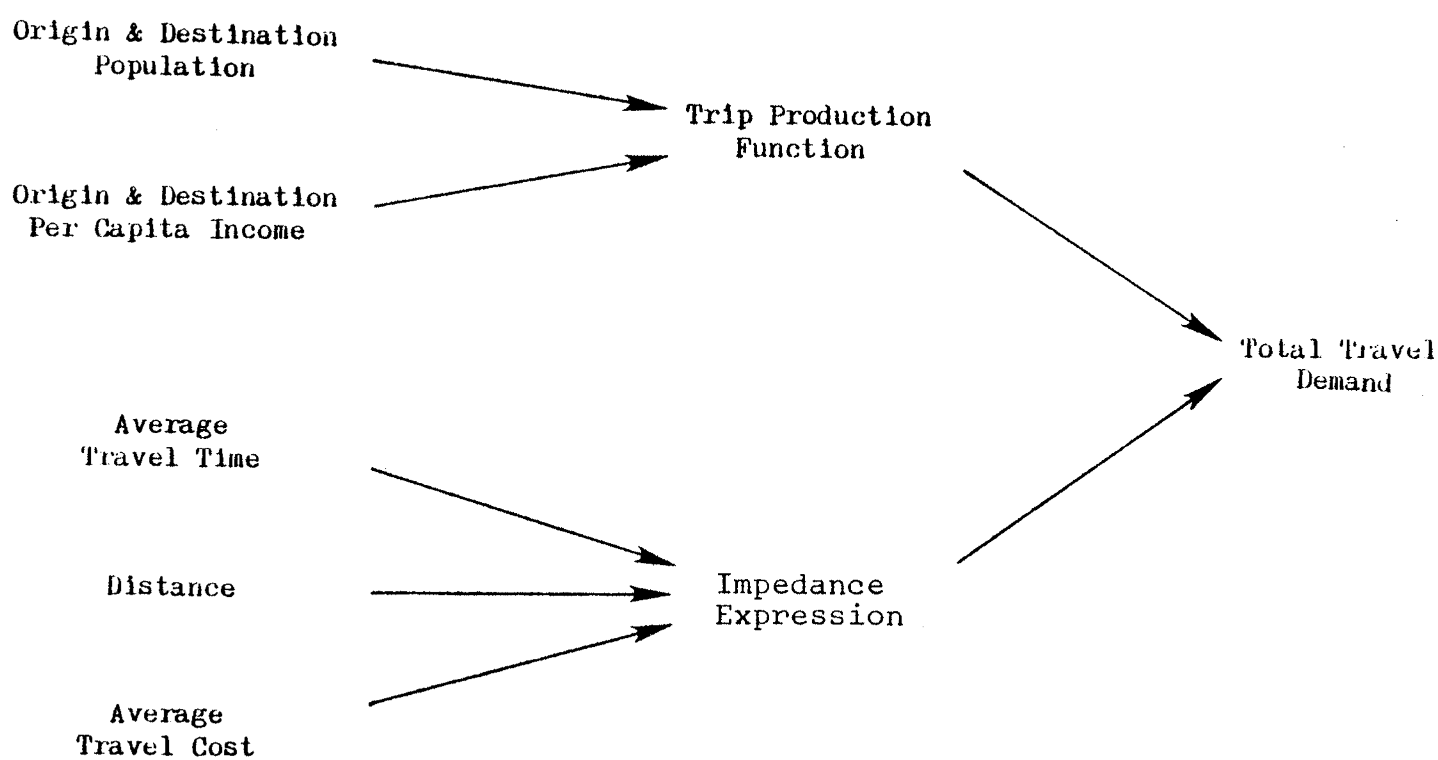

Figure 12. Spaith total demand model.

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Michigan

The model developed for application in and around Michigan was formulated at the Stanford Research Institute.(12) The objective of the model is to accurately forecast intercity passenger demand for a wide range of origins, destinations, and city sizes. Numerous existing models have difficulty in forecasting consistently with a wide range of city sizes. This feature of the model classifies it as a segmented model.

Figure 13 illustrates the relationships of the components of the total travel portion of the model. The structure of the mode split portion of the model is identical to that of the NECTP mode split model in general terms. A unique feature of the total travel demand submodel is the socioeconomic variables used. One variable is used to measure both population and income at the origin and destination cities. The variable is the number of families with incomes exceeding $10,000 in the Standard Metropolitan Statistical Area (SMSA) or county of the origin or destination city.

Model Formulation

$$D = b_o (F_i D_j)^{b_1} W^{b_2} \text{ for } F_i F_j > G$$

$$D = b_o^1 (F_i F_j)^{b_1'} W^{b_2} \text{ for } F_i F_j \leq G$$

$$w = A_m t_m^{a_1} c_m^{a_2} (1 - \exp[-kf_m])^{a_3} \text{ for } m \neq \text{auto}$$

$$w_m = t_m^{a_4} (c_m/1.7)^{a_5} \text{ for } m = \text{auto}$$

$$W = \sum_m w_m$$

$$D_i = D w_m / W,$$

where

w_m = impedance of mode m,

W = total system impedance,

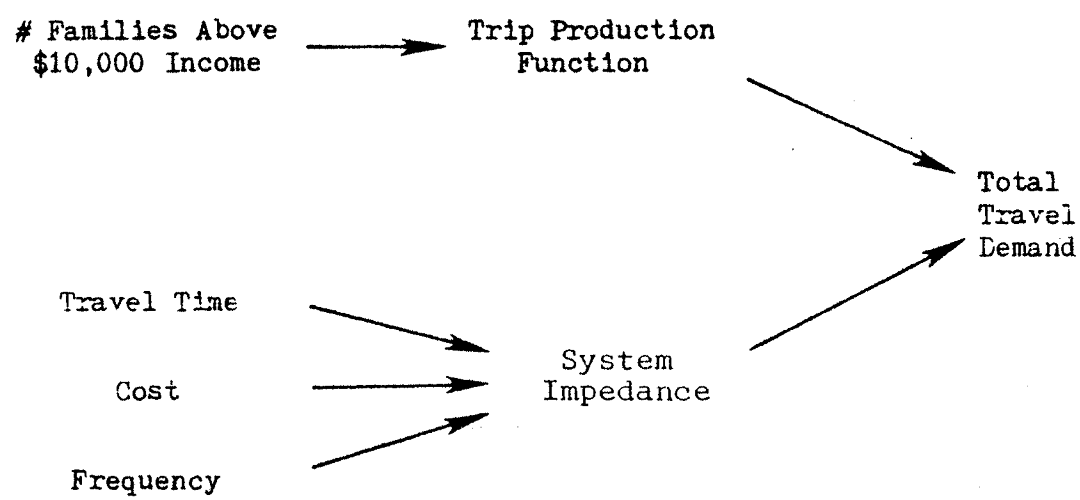

Figure 13. Michigan total demand model.

D = total travel demand,

D_m = travel demand of mode m,

t_m = total travel time of mode m,

c_m = total out-of-pocket cost,

f_m = frequency of service in trips per day,

F = number of families with annual income exceeding $10,000 (families x 10) in the SMSA or county of the origin city or destination city j, and

$b_o, b_1, b_2, b_o^1, b_1^1, b_2^1, a_1, \ldots, a_5$ = calibration coefficients.

Discussion

The parameter G is used to segment the model. It is chosen such that the model is sensitive to various city pair sizes through statistical tests of travel demand data used for calibration of the model. The parameter could prove to be a weakness in the model since various combinations of city pairs could have the same product but different travel patterns.

The mode split portion of the model is slightly different from that of the NECTP mode split model in its treatment of the market share of the automobile. Rather than letting the coefficient a_3 equal zero, as is the case in the NECTP model, an equation is used which assumes an average auto passenger level of 1.7 persons.

New York State Department of Transportation

The model developed by the New York State Department of Transportation (NYSDOT) was used in the investigation of improved rail service in the Buffalo-New York City corridor.(13) It consists of two basic sections: a total travel demand submodel and a binary logit competition mode split submodel. The post-distribution models presented up to this point have incorporated a multinominal logit competition mode split model. The binary logit competition model examines how a specific mode, rail in the NYSDOT study, competes with each of the other available modes individually. A multinominal logit competition model examines how a specific mode competes with all the available modes at once.

Figure 14 illustrates the components of the model. The pivot point analysis utilized in the model is a method of adjusting the

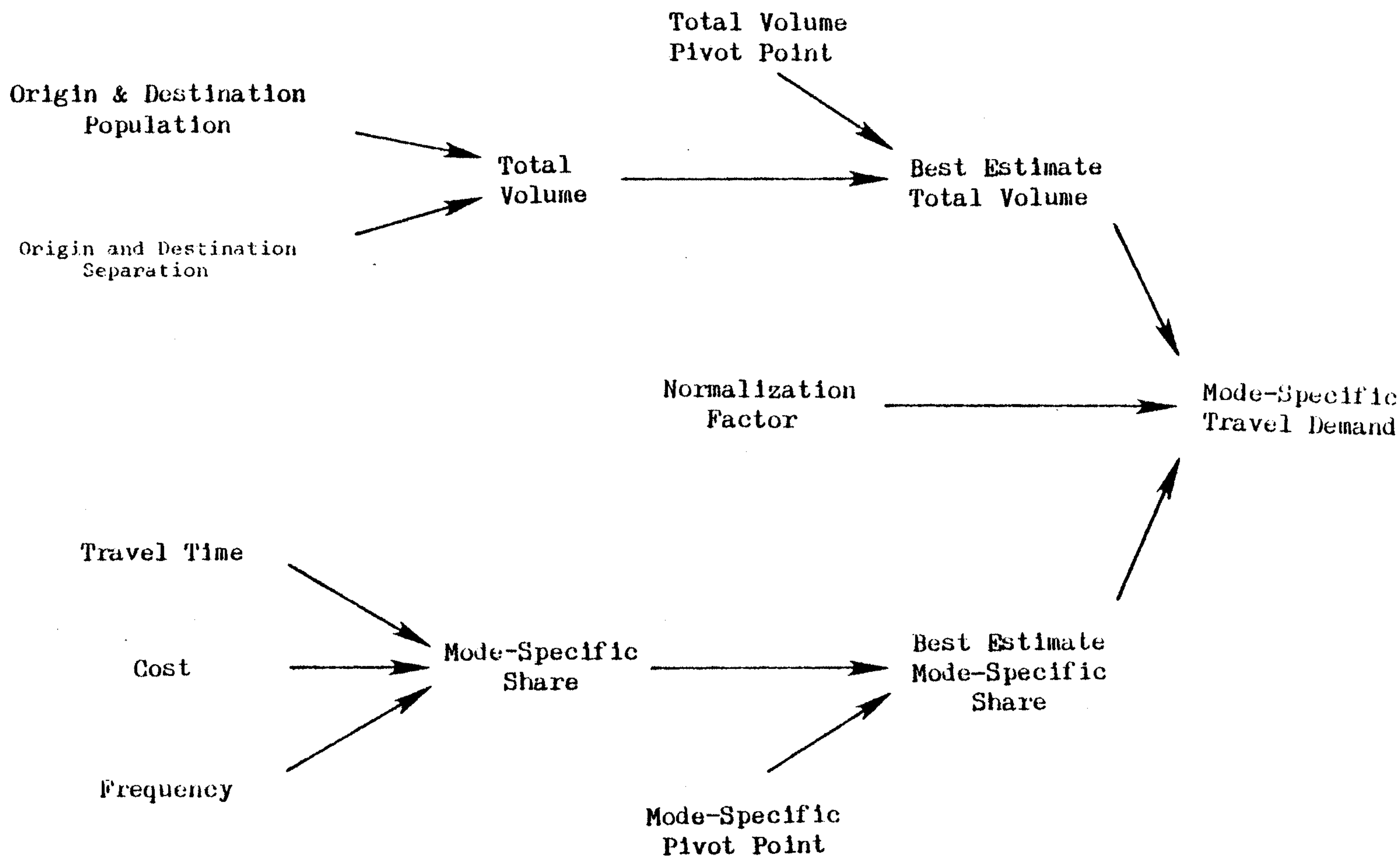

Figure 14. NYSDOT binary travel demand model.

model forecast to reduce residual error. A base year is selected for which data are available. The base year is then forecasted with the model. The ratio between the base year data and the base year forecast is the pivot point adjustment. When this technique is applied to the binary logit competition model, the sum of the modal share is greater than one. Normalization is used to remove the introduced error.

Model Formulation

$$\text{Modal Demand} = (TOT_F) \times \frac{(TOT_B)}{(TOT'_B)} \times (P'_F) \frac{(P_B)}{(P'_B)} \times \frac{1}{\sum_m (P_{mF})} \frac{(P_B)}{(P_{mB})}$$

$$TOT_F = \frac{a(P_i P_j)^b}{t_{ij}{}^c}$$

$$P_F = \frac{1}{1 + \sum_m e - G_m}$$

$$G_m = a_{om} + a_{1m} X_1 + a_{2m} X_2 + \ldots,$$

where

TOT'_F = forecast future total demand,

TOT'_B = forecast total demand for the base year,

TOT_B = actual base year total demand,

P'_F = forecast future modal share,

P'_B = forecast base year modal share,

P_B = actual base year modal share,

P_i, P_j = population of cities i and j,

T_{ij} = travel impedance between cities i and j,

$S_1, S_2, \ldots$ = modal attributes,

a,b,c = calibration coefficients, and

$a_{om}, a_{lm}, \ldots$ = mode-specific calibration coefficients.

Discussion

Modal attributes used in the binary logit competition model are identified through stepwise regression. This results in different system variables being used to determine the modal share. Since various system measures appear in describing binary competition, the model produces information on how the modes compete with each other. For instance, the NYSDOT report concludes that the ratios of air to rail frequency of service and travel time were critical in determining the competitive effects of air service on the rail market share. Food service, the ratio of bus to rail frequency of service, and the difference between bus and rail travel times were important in determining the competitive effects of bus service on the rail market share. This information is valuable in determining policies to improve the market share of a mode.

The total travel demand submodel is a simple gravity model. The travel impedance measure utilized in the model is travel time. Population figures are used to generate traffic. Income measures do not appear in the model.

West Virginia

The model developed for application in West Virginia is a total travel demand model.(14) It does not incorporate a mode split model to forecast modal travel demand. The model is formulated to estimate intercity travel for towns of less than 50,000 population. It is developed for intercity travel and city-to-rural travel and is structured as a modified gravity model.

Figure 15 shows the simplicity of the model structure. Origin and destination city populations are used to generate a measure of total travel. The amount of total travel is impeded by the travel time between the city pair.

Model Formulation

Intercity travel demand is estimated by either of the following two equations:

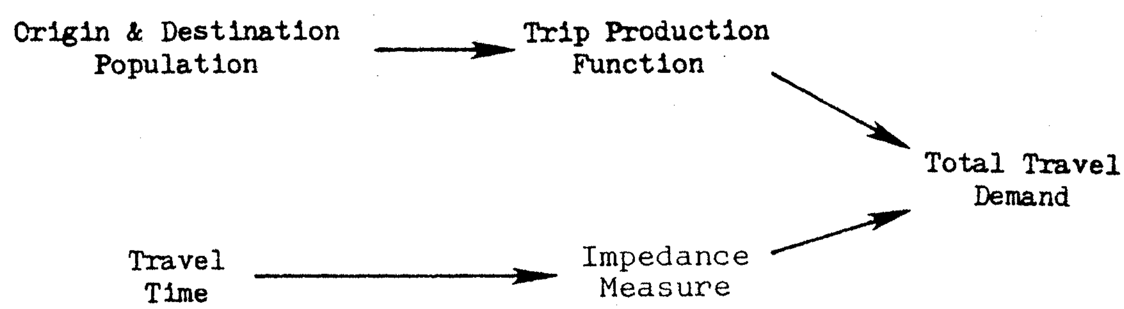

Figure 15. West Virginia total demand model.

1) $T_{ij} = a_o P_i P_j \exp(b_1 D_{ij})$.

2) $T_{ij} = a_1 \frac{(P_i P_j)^{\frac{1}{2}}}{D_{ij}^2} - \frac{a^2 (P_i P_j)^{\frac{1}{2}}}{D_{ij}^2}$.

City-to-rural travel demand is estimated by

$$T_{ij} = a_3 \frac{(P_i + P_j)}{D_{ij}^2},$$

where

T_{ij} = travel demand from city i to city j,

P_i, P_j = population of city i and city j,

D_{ij} = travel time from city i to city j, and

$a_o, \ldots, a_3, b_1$ = calibration coefficients.

Discussion

The second intercity travel demand model gave slightly better forecasts than the first model in the West Virginia study. The calibration coefficient b_1 is negative in the first intercity travel demand model so that the travel time variable functions as an impedance term.

The city-to-rural travel demand model was segmented for three population ranges. The following are values of the calibration coefficient a_3 contained in the model.

Population Range	a_3
greater than 10,000	2.67
5,000 - 10,000	5.11
less than 5,000	10.67

MODEL AND ROUTE SELECTION

This section discusses the selection of intercity travel demand models that would be appropriate for analysis of the Virginia network. The selection of a model(s) was dependent on the availability of input data and the transferability of calibrations. Three models were selected for use in the study and these are described together with the routes within the Virginia network that were analyzed.

Model Selection

In order that models correctly replicate existing conditions, they are calibrated using a data base for the region under study. However, where data are not available or are too costly to obtain, models developed in one area can be used in another. Intercity bus ridership origin-destination was not obtained nor were data on intercity travel by auto or rail. Agencies performing similar studies in other states have examined ticket receipts at bus terminals to obtain origin-destination information but this was not feasible in the present study because of budgetary and time constraints. Accordingly, those models selected for use in this study had been previously calibrated using a statewide intercity travel data base. Eight of the models described earlier had been calibrated and were thought to be possibly appropriate for the present analysis. After examination, it was concluded that three of these models were transferable to Virginia conditions and these were used to investigate intercity bus passenger demand.

The two Canadian models had been sufficiently calibrated, but since they contain a linguistics pairing index they would not be easily adapted to the Virginia intercity travel market. The NYSDOT model is a binary logit model which compares rail travel to all other available modes. Since intercity bus is not calibrated separately, this model would not produce the desired results. The West Virginia model is a total travel model which does not consider modal attributes. The intercity transportation effectiveness model was developed for investigating air travel demand only and does not consider modal competition. Thus, it would appear that of the eleven models reviewed, three are calibrated to meet conditions appropriate to this study. These are the NECTP, SPAITH and MICHIGAN models. These models and their calibrated values are discussed below.

NECTP

The NECTP model has seven calibrations: some are more accurate in their forecasts than others. Three of the models have aggregate calibrations. Two of the models are disaggregated for business and nonbusiness trip purposes. Table 7 presents all the calibrations. The model's formulation is as follows:

$$w_m = C_m t_m^{a_1} c_m^{a_2} (1 - \exp[-kf])^{a_3},$$

where each term in the expression has been defined in the previous section.

Discussion

The model appears with three calibrations — CN22, CN25, and CN26 — which consider frequency of bus service in their calibrated formulations. The other calibrations — CN27 and CN28, business and nonbusiness — have bus frequency coefficients (k and a_3) equal to zero, indicating that the frequency measure of level of service does not affect the relative market share of the intercity bus industry. This cannot be assumed for the Virginia intercity bus market. Therefore, the four calibrations of CN27 and CN28 are discarded for implementation.

The NECTP model was calibrated using 64 city pairs within the northeast corridor. The models were tested for transferability out of the northeast corridor using 44 other city pairs. The results, based on root mean square error, indicated that CN22 was the best overall model and was followed by CN26. For forecasting the intercity bus market share, CN26 ranked first and was followed by CN28.

Calibrations CN22 and CN26 were selected for investigating the Virginia intercity bus network.

Table 7

NECTP Model Calibrations

Model	Mode	C	a_1	a_2	a_3	k
CN22	Air	1.01	-2.23	-1.11	0.53	0.12
	Rail	1.46	-2.23	-1.11	1.05	0.12
	Bus	0.33	-2.23	-1.11	0.05	0.12
	Auto	1.0	-2.32	-1.16	0	0
CN25	Air	1.1144	-1.9102	-0.9551	0.3247	0.12
	Rail	1.1144	-1.9102	-0.9551	0.3247	0.12
	Bus	1.1144	-1.9102	-0.9551	0.3247	0.12
	Auto	1.000	-1.9288	-0.9644	0	0
CN26	Air	1.8978	-1.9135	-0.8555	0.5536	0.007
	Rail	3.8547	-1.9135	-0.8555	0.5536	0.007
	Bus	1.4486	-1.9135	-0.8555	0.5536	0.007
	Auto	1.0	-1.9135	-0.8555	0	0
CN27	Air	1.1232	-3.384	-0.483	2.279	0.12
Business	Rail	1.4813	-3.384	-0.483	2.279	0.12
	Bus	0.3767	-3.384	-0.483	0	0
	Auto	1.0	-3.384	-0.483	0	0
Nonbusiness	Air	0.7767	-1.5821	-1.5821	2.0462	0.18
	Rail	1.9881	-1.5821	-1.5821	1.0462	0.18
	Bus	1.3872	-1.5821	-1.5821	0	0
	Auto	1.0	-1.5821	-1.5821	0	0
CN28B	Air	0.937	-3.384	-0.483	5.587	0.50
Business	Rail	1.2363	-3.384	-0.483	5.587	0.50
	Bus	0.3767	-3.384	-0.483	0	0
	Auto	1.0	-3.384	-0.483	0	0
Nonbusiness	Air	1.1163	-1.5821	-1.5821	5.587	0.672
	Rail	1.4710	-1.5821	-1.5821	5.587	0.672
	Bus	0.9324	-1.5821	-1.5821	0	0
	Auto	1.0	-1.5821	-1.5821	0	0

Spaith

The Spaith travel demand model is broken down into two portions: a total travel submodel and a modal split submodel. The model is an aggregate model with one calibration. The NECTP model calibration CN22 previously presented is used for the modal split submodel. The total travel demand submodel is formulated as

$$T_{ij} = b_o(P_iP_j)^{b_1} (Y_iY_j)^{b_2} \left(\frac{AC_{ij}}{d_{ij}}\right)^{b_3} (AT_{ij})^{b_4}.$$

The calibration coefficients are as follows:

b_o = exp (-46.4),

b_1 = 0.23,

b_2 = 3.40,

b_3 = 0.58, and

b_4 = 1.03.

Discussion

The total travel demand submodel was calibrated using a data base of 150 city pairs from the 1972 National Travel Survey. This is the same survey used by the ICC in its preliminary study of the intercity bus industry. The survey sampled travel characteristics of households. Population and per capita income data were obtained from 1972 figures.

Michigan

The Michigan model is an aggregate travel demand model. The modal split submodel is similar in form to the NECTP modal split model. Automobile travel costs are based on 1.7 persons per auto. The total travel submodel is segmented according to city pair size.

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The total travel formulation is

$$T_{ij} = b_o(F_iF_j)^{b_1} w^{b_2} \text{ for } F_iF_j > G$$

$$T_{ij} = b_o^{'} (F_iF_j)^{b_1^{'}} w^{b_2} \text{ for } F_iF_j \leq G.$$

The modal split formulation is

$$w_m = C_m t_m^{a_1} C_m^{a_2} (1 - \exp[-kf])^{a_3}.$$

The calibration coefficients were identified using a constrained search technique which produced the results presented in Table 8.

Table 8

Michigan Calibration Results

Modal Split Submodel

Coefficient	Air	Rail	Bus	Auto
C	1.50	0.75	0.75	1.0
a_1	-1.50	-1.50	-1.50	-1.50
a_2	-1.50	-1.50	-1.50	-1.50
a_3	0.3247	0.3247	0.3247	0
k	0.12	0.12	0.12	0

Total Travel Submodel

b_o = 25,000 b_o = 2,500

b_1 = 1.0 b_1 = 0.1

b_2 = 0.9

G = 0.075

The Virginia Network

The Virginia intercity bus network is comprised of five regular route carriers (see Figure 16). Greyhound Lines, Inc. and Trailways, Inc. provide service throughout the state. James River Bus Lines is based in Richmond and serves the outlying regions. Bristol-Jenkins Bus Lines, Inc. provides service in the western tip of the state and the D&M Bus Company serves Martinsville and Danville in the southern portion of the state.

Service is provided to approximately 300 principal communities. In addition, other small communities are serviced through flag stops and nearby highway stops. Two types of route service are present in the state. Greyhound Lines, Inc. and Trailways, Inc. operate routes which primarily originate or terminate in major population centers of the south, such as Miami; southwest, such as Dallas; and in the northeast, such as New York City. James River Bus Lines, Bristol-Jenkins Bus Lines, Inc. and the D & M Bus Company operate routes which provide service that is more regional in nature.

Route Selection

The objective of the route selection task was to identify routes throughout the state which are representative of the Virginia intercity bus network. The selected routes are reflective of the dynamics of the level of service parameters and travel demand.

The ICC report indicates that a form of cross-subsidization occurs in the intercity bus industry. High density route revenues are used to offset the losses of low density routes . Government regulation prevents intercity bus operators from discontinuing service on unprofitable routes without approval. Therefore, the high volume route between Washington, D. C. and Richmond was not included in the sample network. The level of service for this city pair was disproportionally high compared to that of other Virginia city pairs. The variety of travel times and costs for the intercity bus result in average values for those measures of service that are unrepresentative of the service provided throughout the state.

Figure 17 indicates the routes selected. Either Trailways, Inc. and/or Greyhound Lines, Inc. operate over the routes. Table 9 lists the origin-destination city pairs which comprise the sample network. The sample includes 19 cities and 138 one-way city pairs. A majority of the population centers in Virginia are included in the sample.

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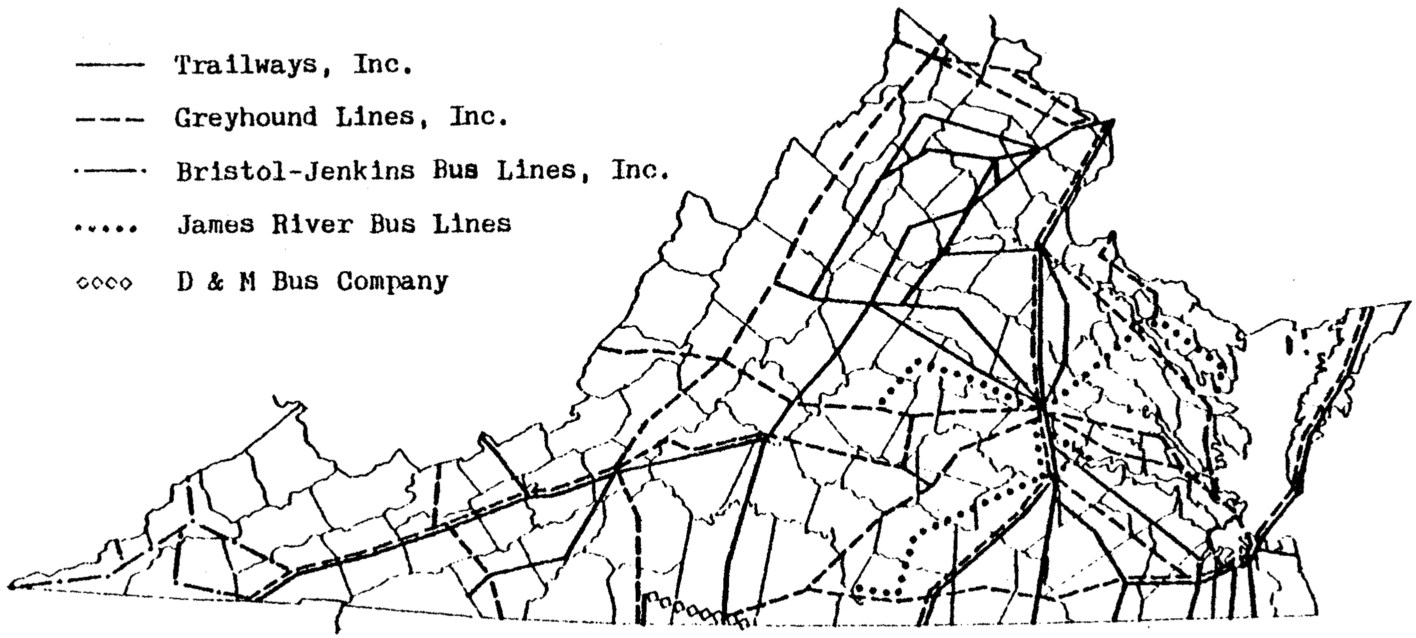

Figure 16. The Virginia intercity bus network.

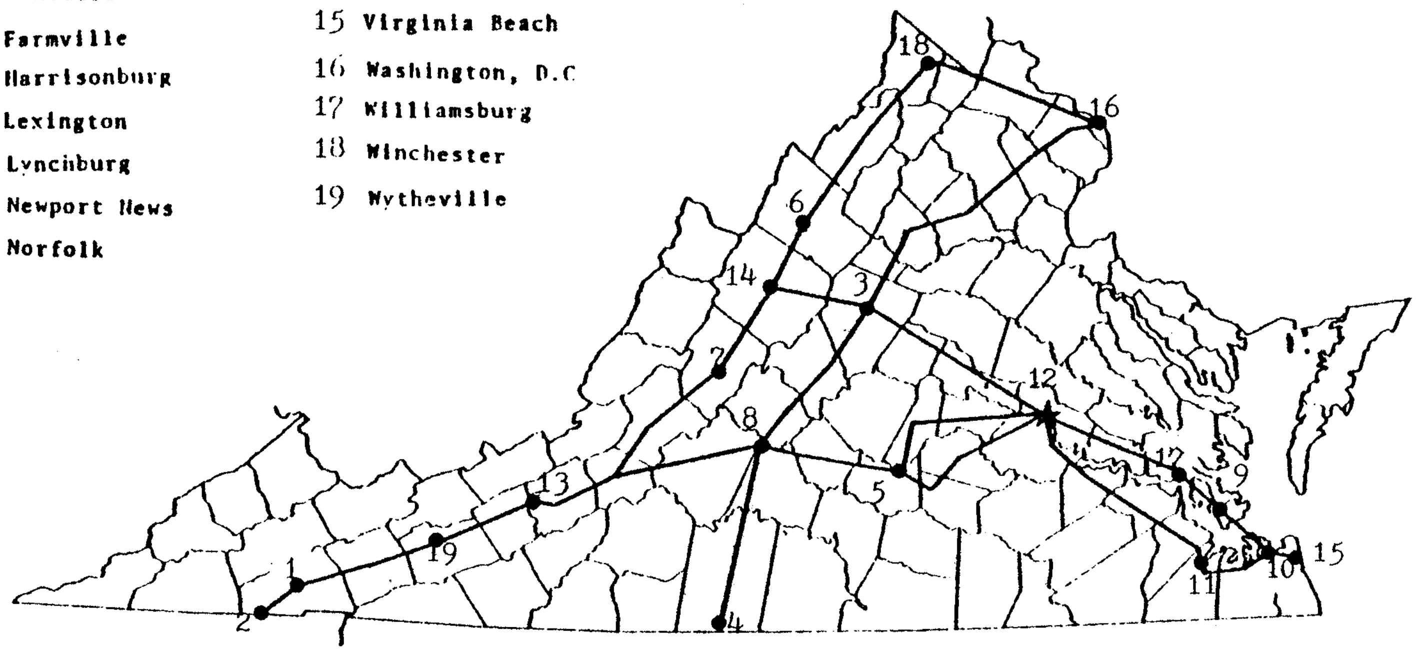

Figure 17. Sample network.

Table 9

Sample Network Origin - Destination Pairs

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon		•	•			•	•	•					•			•		•	•
Bristol	•		•			•	•	•					•			•		•	•
Charlottesville	•	•		•				•				•	•	•		•			
Danville			•					•								•			
Farmville								•				•	•						
Harrisonburg	•	•					•						•	•		•		•	•
Lexington	•	•				•							•	•		•		•	•
Lynchburg	•	•	•	•	•							•	•			•			
Newport News										•	•	•			•		•		
Norfolk									•		•	•			•		•		
Portsmouth									•	•		•			•		•		
Richmond			•		•			•	•	•	•		•	•	•		•		
Roanoke	•	•	•		•	•	•	•				•		•		•		•	•
Staunton			•			•	•					•	•			•		•	•
Virginia Beach									•	•	•	•					•		
Washington, D.C.	•	•	•	•		•	•	•					•	•				•	•
Williamsburg									•	•	•	•			•				
Winchester	•	•				•	•						•	•		•			•
Wytheville	•	•				•	•						•	•		•		•	

NETWORK DATA

This section describes the data for each mode (air, rail, bus, auto) of the Virginia intercity network evaluated in this study. The section includes sources of information and socioeconomic data such as population and per capita income for each of the cities served, and describes intercity network characteristics of travel time, cost, and frequency of service.

Data Collection

Socioeconomic data were obtained from the 1970 Census of the Population and the Virginia Department of Highways and Transportation. Air level of service data (travel time, fares, and frequency of service) were obtained from the May 1978 Official Airline Guide. Rail service data were obtained from Southern Railways and Amtrak. Travel time and frequency of service information for intercity bus was obtained from the December 1978 Russell's Official Motor Coach Guide. Fare structure information was obtained by contacts with the operators. Intercity auto cost and travel time were derived from highway mileage.

Socioeconomic Data

The socioeconomic data (Table 10) consist of population, per capita income, and the number of families with annual incomes of less than $10,000 in the SMSA or county of the origin and destination cities. The populations range from 4,447 persons in Abingdon to 756,000 persons in Washington, D. C. Per capita incomes range from $2,376 in Bristol to $3,859 in Washington, D. C. The number of families with an annual income of less than $10,000 varied from 1,380 in Wytheville to 453,570 in Washington, D. C.

Two cities (Bristol and Abingdon) are located in the same county and three cities (Norfolk, Portsmouth, and Virginia Beach) are located within the same SMSA. Use of these data will produce error in the Michigan model forecasts since the socioeconomic variable used to generate travel pertains to the SMSA or county of the origin and destination cities. Therefore, when the Michigan model was used to forecast both total and bus travel demand, the city pairs of Abingdon-Bristol, Norfolk-Portsmouth, Norfolk-Virginia Beach, and Portsmouth-Virginia Beach were excluded from the investigation.

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Table 10

Socioeconomic Characteristics

Town	Population	Per Capita Income ($)	No. of families with less than $10,000 Income (x10-5)
Abingdon*	4,447	2,552	0.0245
Bristol*	14,854	2,376	.0245
Charlottesville	38,880	3,190	.0399
Danville	46,391	2,796	.0373
Farmville	4,203	2,748	.0093
Harrisonburg	14,605	2,742	.0375
Lexington	7,597	2,581	.0118
Lynchburg	54,083	3,045	.1290
Newport News	138,177	3,034	.3353
Norfolk*	307,951	2,797	.6540
Portsmouth*	110,963	2,636	.6540
Richmond	249,621	3,168	.6668
Roanoke	92,115	2,935	.2116
Staunton	24,504	2,888	.0409
Virginia Beach*	172,106	3,098	.6540
Washington, D.C.	756,510	3,859	4.5357
Williamsburg	9,069	3,066	.0158
Winchester	14,643	2,954	.0268
Wytheville	5,893	2,840	0.0138

* belong to same SMSA or county

Intercity Travel Network Data

The network data consist of travel time, cost, and frequency of service for air, auto, bus, and rail modes. Travel time is measured from door to door using an estimate of 15 minutes for accessing and egressing the terminal. The cost data are measured as out-of-pocket cost, and frequency of service is in units of number of departures per day.

Air Network Data

Figure 18 illustrates the Virginia nonstop flight system operating in May 1978. Nine cities in the sample network had nonstop flight service; namely, Charlottesville, Danville, Lynchburg, Newport News, Norfolk, Richmond, Roanoke, and Staunton. In the figure, all routes except that between Staunton and Charlottesville provide nonstop and round-trip service. Service between Charlottesville and Staunton is provided only in the westbound direction. Round-trip and nonstop service is available between Roanoke and Washington, D. C. and between Charlottesville and D. C.

Tables 11, 12, and 13 contain travel time, travel cost, and frequency for all flights connecting the nine cities, including direct flights with intermediate stops.

For the Charlottesville-Danville city pair, there is service from Danville to Charlottesville but not in the reverse direction (with an intermediate stop in Lynchburg).

Rail Network Data

Figure 19 illustrates the intercity rail service pertaining to the sample network. During 1978 service was provided by Amtrak and the Southern Railroad. Amtrak operated service between Washington, D. C. and Charlottesville and between Richmond and Norfolk. The Southern Railroad operated the Southern Crescent serving Washington, D. C., Charlottesville, Lynchburg, and Danville.

Table 14 contains travel time, cost, and frequency of service information for the Southern Crescent. The fare structure used in May 1978 is based on a cost rate of 7.092¢ per mile. Amtrak's Cardinal service was assumed to be the same as that of the Southern Crescent. Amtrak was unable to provide information on the Norfolk-Richmond route.

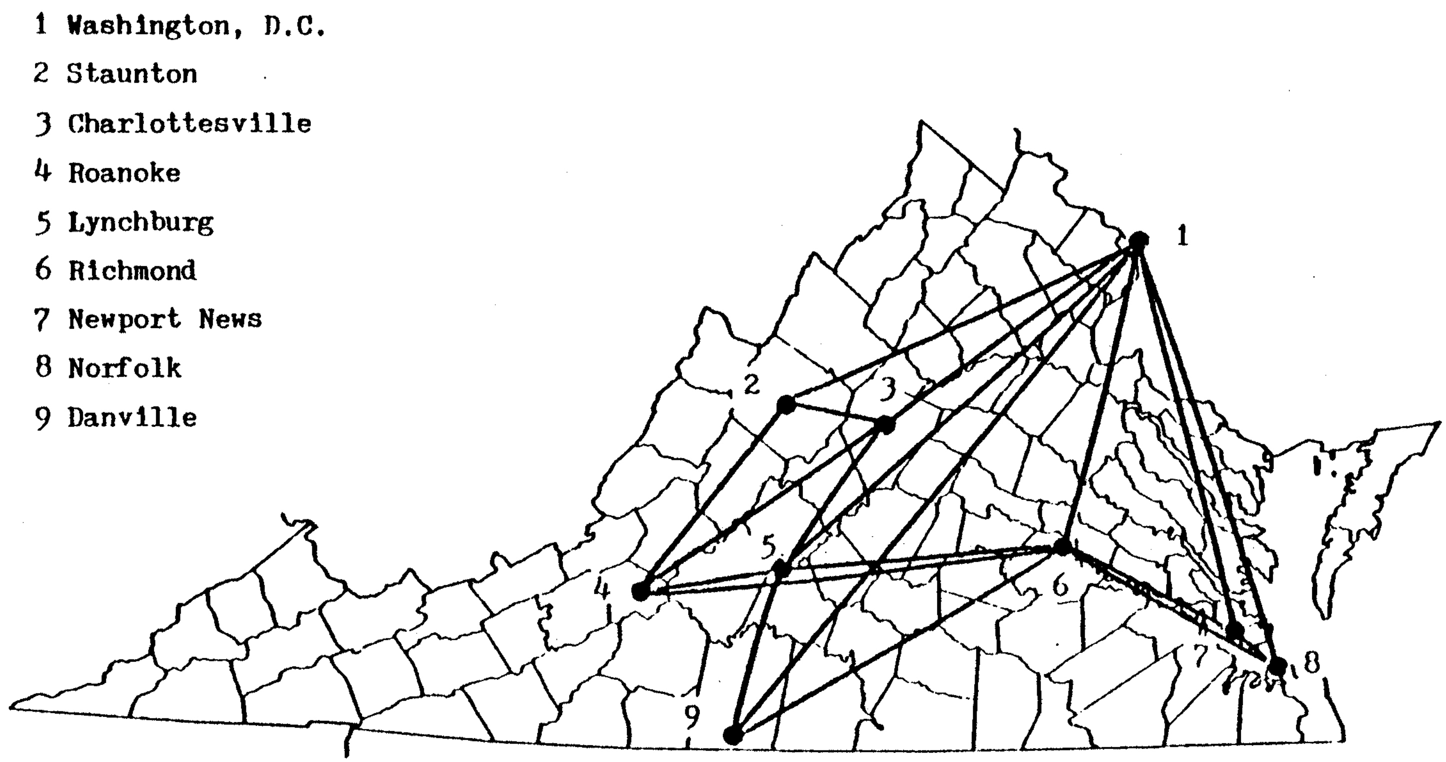

Figure 18. The Virginia direct flight network.

Table 11

Air Travel Time, hours

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bristol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Charlottesville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.38	1.90	0.00	0.00	0.00	.45	.30	0.00	.60	0.00	0.00	0.00
Danville	0.00	0.00	1.07	0.00	0.00	0.00	0.00	.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.97	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lexington	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lynchburg	0.00	0.00	.40	.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.33	0.00	0.00	.70	0.00	0.00	0.00
Newport News	0.00	0.00	1.87	0.00	0.00	0.00	0.00	0.00	0.00	.25	0.00	.38	.52	2.50	0.00	.75	0.00	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.45	1.40	0.00	0.00	.61	0.00	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Richmond	0.00	0.00	0.00	.72	0.00	0.00	0.00	0.00	.38	.42	0.00	0.00	.57	0.00	0.00	.53	0.00	0.00	0.00
Roanoke	0.00	0.00	.07	0.00	0.00	0.00	0.00	.33	1.38	1.42	0.00	.75	0.00	.52	0.00	.67	0.00	0.00	0.00
Staunton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.55	0.00	0.00	.68	0.00	0.00	0.00
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Washington, D.C.	0.00	0.00	.62	1.60	0.00	0.00	0.00	.90	.65	.72	0.00	.50	.72	.72	0.00	0.00	0.00	0.00	0.00
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Winchester	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wytheville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Table 12

Air Fare, dollars

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bristol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Charlottesville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.00	37.00	0.00	0.00	0.00	37.00	28.00	0.00	34.00	0.00	0.00	0.00
Danville	0.00	0.00	40.00	0.00	0.00	0.00	0.00	31.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.00	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lexington	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lynchburg	0.00	0.00	33.00	31.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00	0.00	0.00	42.00	0.00	0.00	0.00
Newport News	0.00	0.00	37.00	0.00	0.00	0.00	0.00	0.00	0.00	27.00	0.00	31.00	46.00	38.00	0.00	34.00	0.00	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.00	46.00	0.00	0.00	34.00	0.00	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Richmond	0.00	0.00	0.00	42.00	0.00	0.00	0.00	0.00	31.00	32.00	0.00	0.00	44.00	0.00	0.00	29.00	0.00	0.00	0.00
Roanoke	0.00	0.00	37.00	0.00	0.00	0.00	0.00	30.00	46.00	46.00	0.00	44.00	0.00	36.00	0.00	44.00	0.00	0.00	0.00
Staunton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.00	0.00	0.00	35.00	0.00	0.00	0.00
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Washington, D.C	0.00	0.00	34.00	43.00	0.00	0.00	0.00	42.00	34.00	34.00	0.00	29.00	44.00	35.00	0.00	0.00	0.00	0.00	0.00
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Winchester	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wytheville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 13

Frequency of Air Service, departures per day

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bristol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Charlottesville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	4.00	0.00	0.00	0.00
Danville	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lexington	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lynchburg	0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	5.00	0.00	0.00	0.00
Newport News	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	1.00	1.00	1.00	0.00	3.00	0.00	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	5.00	0.00	0.00	12.00	0.00	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Richmond	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	6.00	0.00	0.00	6.00	0.00	0.00	11.00	0.00	0.00	0.00
Roanoke	0.00	0.00	1.00	0.00	0.00	0.00	0.00	2.00	1.00	3.00	0.00	3.00	0.00	1.00	0.00	8.00	0.00	0.00	0.00
Staunton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	3.00	0.00	0.00	0.00
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Washington, D.C.	0.00	0.00	3.00	2.00	0.00	0.00	0.00	6.00	3.00	13.00	0.00	10.00	10.00	3.00	0.00	0.00	0.00	0.00	0.00
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Winchester	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wytheville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

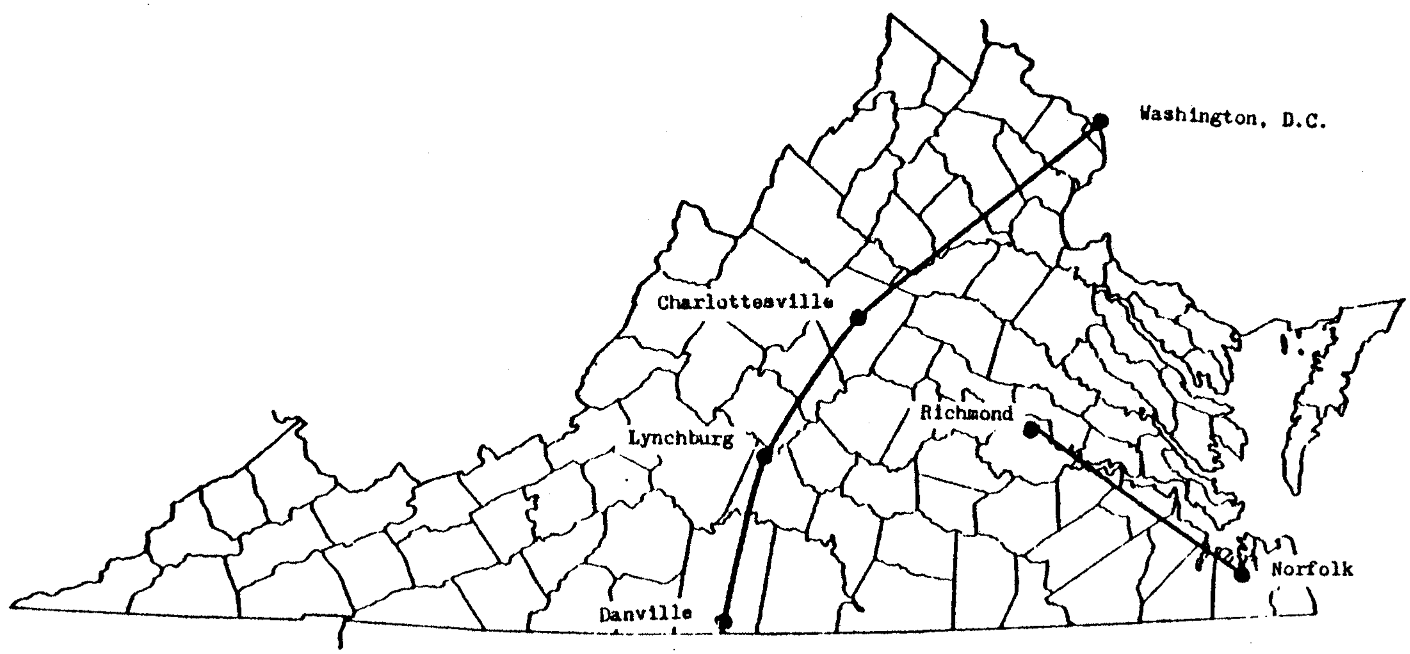

Figure 19. The sample Virginia rail network.

Table 14

Intercity Rail Service Data

			Distance, miles	Travel Time, hours	Cost, dollars	Frequency (depart/day)
Washington, D. C.	—	Charlottesville	112	2.25	7.95	2
	—	Lynchburg	173	3.57	12.30	1
	—	Danville	236	2.73	16.75	1
Charlottesville	—	Lynchburg	61	1.32	4.35	1
	—	Danville	124	2.50	8.80	1
Lynchburg	—	Danville	63	1.25	4.50	1

Northbound service departs from Danville at 3:30 a.m., from Lynchburg at 4:45 a.m., and from Charlottesville at 5:45 a.m. and 6:00 a.m. Southbound service departs from Charlottesville at 9:35 p.m. and midnight, from Lynchburg at 10:45 p.m., and from Danville at 12:20 p.m. With service at these times, there is a significant degree of inconvenience involved in riding the train. This factor is not reflected in the data.

Amtrak service between Richmond and Norfolk was not estimated. It was possible to determine the Richmond-Norfolk fare using the Southern Crescent fare rate. However, travel times and frequency of service data could not be reasonably estimated.

Intercity Bus Network Data

The complete Virginia intercity bus network was presented in Figure 16 and the sample network was presented in Figure 17. Tables 15-17 contain data on travel time, cost, and frequency of intercity bus service for the sample network. The data vary for specific city pairs by direction of travel. Data are shown for one-way travel, since the level of service will vary for each direction of a round trip. The frequency of service is more likely to vary for opposite directions of a city pair than would cost or travel time.

Auto Network Data

Auto network data are based on the distance between the origin and destination. The average travel time for each city pair of the sample network was calculated assuming an average speed of 45 mph (77 km/h). This assumes travel on the highway to be approximately 55 mph (88 km/h) with some slower speeds for access and egress.

The automobile travel cost was difficult to estimate because of increases in fuel cost and increases in automobile fuel efficiency. The U. S. Department of Transportation (DOT) estimates automobile travel cost as

$$C_{ij} = \frac{\$0.04 \text{ per mile } (D_{ij}) + \text{tolls}}{2.0},$$

where

C_{ij} = out-of-pocket automobile cost per person, and

D_{ij} = highway mileage between i and j.

Table 15

Bus Travel Time, hours

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	.25	5.75	0.00	0.00	6.75	5.17	4.50	0.00	0.00	0.00	0.00	2.67	0.00	0.00	8.33	0.00	8.67	1.17
Bristol	.25	0.00	6.08	0.00	0.00	6.00	4.58	4.92	0.00	0.00	0.00	0.00	2.92	0.00	0.00	8.75	0.00	8.00	1.42
Charlottesville	5.75	6.08	0.00	3.17	0.00	0.00	0.00	1.42	0.00	0.00	0.00	1.33	2.67	1.00	0.00	2.50	0.00	0.00	0.00
Danville	0.00	0.00	3.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.58	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.50	2.25	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	6.75	6.00	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00	2.50	.58	0.00	3.33	0.00	1.42	4.25
Lexington	5.17	4.58	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00	0.00	1.00	.83	0.00	5.17	0.00	3.33	2.75
Lynchburg	4.42	5.75	1.50	1.58	1.00	0.00	0.00	0.00	0.00	0.00	0.00	2.67	1.17	0.00	0.00	4.00	0.00	0.00	0.00
Newport News	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.83	.67	1.83	0.00	0.00	1.42	0.00	.83	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.83	0.00	.17	1.92	0.00	0.00	.42	0.00	1.67	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.67	.17	0.00	2.08	0.00	0.00	.83	0.00	1.58	0.00	0.00
Richmond	0.00	0.00	1.42	0.00	1.50	0.00	0.00	2.67	1.83	1.92	2.08	0.00	3.75	2.67	2.42	0.00	1.00	0.00	0.00
Roanoke	2.67	2.92	2.67	0.00	2.25	2.50	1.00	1.17	0.00	0.00	0.00	4.00	0.00	2.08	0.00	5.50	0.00	4.42	1.50
Staunton	0.00	0.00	1.08	0.00	0.00	.75	.75	0.00	0.00	0.00	0.00	2.58	2.08	0.00	0.00	3.42	0.00	2.92	3.92
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	.42	.83	2.42	0.00	0.00	0.00	0.00	2.33	0.00	0.00
Washington, D.C.	8.38	8.75	2.33	5.08	0.00	3.33	5.17	3.50	0.00	0.00	0.00	0.00	5.50	3.42	0.00	0.00	0.00	1.75	7.50
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.83	1.67	1.58	1.00	0.00	0.00	2.33	0.00	0.00	0.00	0.00
Winchester	8.67	8.10	0.00	0.00	0.00	1.42	3.33	0.00	0.00	0.00	0.00	0.00	4.42	2.92	0.00	1.75	0.00	0.00	4.42
Wytheville	1.17	1.42	0.00	0.00	0.00	4.25	2.75	0.00	0.00	0.00	0.00	0.00	1.50	3.92	0.00	7.50	0.00	4.42	0.00

Table 16

Bus Fare, dollars

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	1.45	18.25	0.00	0.00	18.90	14.35	13.20	0.00	0.00	0.00	0.00	10.15	0.00	0.00	26.15	0.00	23.75	4.30
Bristol	1.45	0.00	19.55	0.00	0.00	20.85	16.30	14.50	0.00	0.00	0.00	0.00	12.10	0.00	0.00	27.50	0.00	25.70	5.25
Charlottesville	18.25	19.55	0.00	9.80	0.00	0.00	0.00	5.05	0.00	0.00	0.00	5.45	8.10	3.05	0.00	7.40	0.00	0.00	0.00
Danville	0.00	0.00	9.80	0.00	0.00	0.00	0.00	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.35	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.95	0.00	0.00	0.00	5.10	7.85	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	18.90	20.85	0.00	0.00	0.00	0.00	4.75	0.00	0.00	0.00	0.00	0.00	8.75	2.10	0.00	10.55	0.00	5.05	14.95
Lexington	14.35	16.30	0.00	0.00	0.00	4.75	0.00	0.00	0.00	0.00	0.00	0.00	4.20	2.95	0.00	13.00	0.00	9.70	8.40
Lynchburg	13.20	14.60	5.05	4.20	3.95	0.00	0.00	0.00	0.00	0.00	0.00	8.65	3.05	0.00	0.00	11.15	0.00	0.00	0.00
Newport News	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	2.25	6.10	0.00	0.00	3.00	0.00	2.45	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	0.00	.90	7.60	0.00	0.00	.75	0.00	4.15	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	.90	0.00	7.60	0.00	0.00	1.65	0.00	4.15	0.00	0.00
Richmond	0.00	0.00	5.45	0.00	5.10	0.00	0.00	8.65	6.10	7.60	7.60	0.00	12.45	8.30	8.35	0.00	3.95	0.00	0.00
Roanoke	10.15	12.10	8.10	0.00	7.85	8.75	4.20	3.05	0.00	0.00	0.00	12.45	0.00	7.10	0.00	15.40	0.00	13.60	6.20
Staunton	0.00	0.00	3.05	0.00	0.00	2.10	2.95	0.00	0.00	0.00	0.00	8.30	7.10	0.00	0.00	10.60	0.00	6.90	13.30
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	.75	1.65	8.35	0.00	0.00	0.00	0.00	4.90	0.00	0.00
Washington, D.C.	26.15	27.60	7.40	15.35	0.00	10.55	13.00	11.15	0.00	0.00	0.00	0.00	15.40	10.60	0.00	0.00	0.00	5.25	21.60
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.45	4.15	4.15	3.95	0.00	0.00	4.90	0.00	0.00	0.00	0.00
Winchester	23.75	25.70	0.00	0.00	0.00	5.05	9.70	0.00	0.00	0.00	0.00	0.00	13.60	6.90	0.00	5.25	0.00	0.00	19.80
Wytheville	4.30	5.25	0.00	0.00	0.00	14.95	8.40	0.00	0.00	0.00	0.00	0.00	6.20	13.30	0.00	21.60	0.00	19.80	0.00

Table 17

Bus Frequency of Service, departures per day

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	9.00	4.00	0.00	0.00	2.00	2.00	3.00	0.00	0.00	0.00	0.00	7.00	0.00	0.00	7.00	0.00	2.00	2.00
Bristol	7.00	0.00	5.00	0.00	0.00	3.00	2.00	3.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	9.00	0.00	3.00	1.00
Charlottesville	5.00	5.00	0.00	6.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00	5.00	5.00	7.00	0.00	13.00	0.00	0.00	0.00
Danville	0.00	0.00	7.00	0.00	0.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	3.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	4.00	4.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00	0.00	4.00	0.00	4.00	4.00
Lexington	4.00	3.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	4.00	0.00	4.00	0.00	4.00	4.00
Lynchburg	2.00	2.00	10.00	7.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	4.00	0.00	0.00	10.00	0.00	0.00	0.00
Newport News	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	12.00	9.00	0.00	0.00	3.00	0.00	9.00	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	17.00	20.00	0.00	0.00	9.00	0.00	9.00	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.00	18.00	0.00	19.00	0.00	0.00	1.00	0.00	9.00	0.00	0.00
Richmond	0.00	0.00	5.00	0.00	4.00	0.00	0.00	4.00	9.00	19.00	18.00	0.00	4.00	5.00	5.00	0.00	9.00	0.00	0.00
Roanoke	9.00	9.00	5.00	0.00	3.00	4.00	4.00	6.00	0.00	0.00	0.00	3.00	0.00	4.00	0.00	10.00	0.00	4.00	5.00
Staunton	0.00	0.00	5.00	0.00	0.00	4.00	5.00	0.00	0.00	0.00	0.00	5.00	4.00	0.00	0.00	4.00	0.00	4.00	4.00
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	8.00	3.00	2.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Washington, D.C	9.00	9.00	12.00	7.00	0.00	5.00	5.00	9.00	0.00	0.00	0.00	0.00	10.00	5.00	0.00	0.00	0.00	6.00	4.00
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	10.00	10.00	9.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00
Winchester	3.00	3.00	0.00	0.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	0.00	6.00	0.00	0.00	3.00
Wytheville	1.00	3.00	0.00	0.00	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	0.00	4.00	0.00	3.00	0.00

This formula assumes an average vehicle occupancy of 2.0 persons.[15] The formula was developed in 1973 for ten major intercity corridors in the United States before energy costs dramatically increased.

The fuel cost was approximately $0.70 per gallon ($0.19 per liter) in May 1978 and the average automobile efficiency was approximately 15 mpg (6 km/l). To check the DOT formula, the Charlottesville-Washington, D. C. city pair was chosen. The gasoline cost for a one-way trip was calculated as $2.66 per person, assuming a 2.0-person occupancy, whereas the DOT formula estimated a cost of $2.28 per person.

The travel mileage used for calculating travel time and cost was taken from a Virginia highway map. When the mileage differed between the mileage table and link total, the link total was used. Tables 18 and 19 contain the travel time and cost calculation results and Table 20 contains the highway mileages.

Table 18

Auto Travel Time, hours

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	.40	5.39	0.00	0.00	5.21	3.86	4.08	0.00	0.00	0.00	0.00	2.86	0.00	0.00	8.07	0.00	6.74	1.29
Bristol	.40	0.00	5.79	0.00	0.00	5.61	4.26	4.48	0.00	0.00	0.00	0.00	3.26	0.00	0.00	8.47	0.00	7.14	1.68
Charlottesville	5.39	5.79	0.00	2.75	0.00	0.00	0.00	1.31	0.00	0.00	0.00	1.62	2.53	.69	0.00	2.53	0.00	0.00	0.00
Danville	0.00	0.00	2.75	0.00	0.00	0.00	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.28	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	0.00	0.00	0.00	1.60	2.27	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	5.21	5.61	0.00	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	2.35	.60	0.00	2.86	0.00	1.53	3.92
Lexington	3.86	4.26	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	0.00	1.00	.84	0.00	4.21	0.00	2.88	2.57
Lynchburg	4.08	4.48	1.31	1.44	1.17	0.00	0.00	0.00	0.00	0.00	0.00	2.66	1.22	0.00	0.00	3.83	0.00	0.00	0.00
Newport News	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.44	.51	1.57	0.00	0.00	.82	0.00	.51	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.44	0.00	.07	2.02	0.00	0.00	.38	0.00	.95	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.51	.07	0.00	2.08	0.00	0.00	.44	0.00	1.02	0.00	0.00
Richmond	0.00	0.00	1.62	0.00	1.60	0.00	0.00	2.66	1.57	2.02	2.08	0.00	4.20	2.31	2.15	0.00	1.06	0.00	0.00
Roanoke	2.86	3.26	2.53	0.00	2.27	2.35	1.00	1.22	0.00	0.00	0.00	4.20	0.00	1.75	0.00	5.14	0.00	3.88	1.57
Staunton	0.00	0.00	.69	0.00	0.00	.60	.84	0.00	0.00	0.00	0.00	2.31	1.75	0.00	0.00	3.44	0.00	2.11	3.33
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.82	.38	.44	2.15	0.00	0.00	0.00	0.00	1.31	0.00	0.00
Washington, D.C.	8.07	8.47	2.53	5.28	0.00	2.86	4.21	3.83	0.00	0.00	0.00	0.00	5.14	3.44	0.00	0.00	0.00	1.33	6.78
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.51	.95	1.02	1.06	0.00	0.00	1.31	0.00	0.00	0.00	0.00
Winchester	6.74	7.14	0.00	0.00	0.00	1.53	2.88	0.00	0.00	0.00	0.00	0.00	3.88	2.11	0.00	1.33	0.00	0.00	5.45
Wytheville	1.29	1.68	0.00	0.00	0.00	3.92	2.57	0.00	0.00	0.00	0.00	0.00	1.57	3.33	0.00	6.78	0.00	5.45	0.00

Table 19

Auto Out-of-Pocket Cost, dollars

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0.00	.36	4.86	0.00	0.00	4.70	3.48	3.68	0.00	0.00	0.00	0.00	2.58	0.00	0.00	7.28	0.00	6.08	1.16
Bristol	.36	0.00	5.22	0.00	0.00	5.06	3.84	4.04	0.00	0.00	0.00	0.00	2.94	0.00	0.00	7.64	0.00	6.44	1.52
Charlottesville	4.86	5.22	0.00	2.48	0.00	0.00	0.00	1.18	0.00	0.00	0.00	1.46	2.28	.62	0.00	2.28	0.00	0.00	0.00
Danville	0.00	0.00	2.48	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.76	0.00	0.00	0.00
Farmville	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	1.46	3.96	0.00	0.00	0.00	0.00	0.00	0.00
Harrisonburg	4.70	5.06	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	2.12	.54	0.00	2.58	0.00	1.38	3.54
Lexington	3.48	3.84	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	.90	.76	0.00	3.80	0.00	2.60	2.32
Lynchburg	3.68	4.04	1.18	1.30	1.06	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.10	0.00	0.00	3.46	0.00	0.00	0.00
Newport News	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.40	.46	1.42	0.00	0.00	.74	0.00	.46	0.00	0.00
Norfolk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.40	0.00	.06	1.82	0.00	0.00	.34	0.00	.86	0.00	0.00
Portsmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.46	.06	0.00	1.88	0.00	0.00	.40	0.00	.92	0.00	0.00
Richmond	0.00	0.00	1.46	0.00	1.46	0.00	0.00	2.40	1.42	1.82	1.88	0.00	3.78	2.08	1.94	0.00	.96	0.00	0.00
Roanoke	2.58	2.94	2.28	0.00	3.96	2.12	.90	1.10	0.00	0.00	0.00	3.78	0.00	1.58	0.00	4.64	0.00	3.50	1.42
Staunton	0.00	0.00	.62	0.00	0.00	.54	.76	0.00	0.00	0.00	0.00	2.08	1.58	0.00	0.00	3.10	0.00	1.90	3.00
Virginia Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.74	.34	.40	1.94	0.00	0.00	0.00	0.00	1.18	0.00	0.00
Washington, D.C.	7.28	7.64	2.28	4.76	0.00	2.58	3.80	3.46	0.00	0.00	0.00	0.00	4.64	3.10	0.00	0.00	0.00	1.20	6.12
Williamsburg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.46	.86	.92	.96	0.00	0.00	1.18	0.00	0.00	0.00	0.00
Winchester	6.08	6.44	0.00	0.00	0.00	1.38	2.60	0.00	0.00	0.00	0.00	0.00	3.50	1.90	0.00	1.20	0.00	0.00	4.92
Wytheville	1.16	1.52	0.00	0.00	0.00	3.54	2.32	0.00	0.00	0.00	0.00	0.00	1.42	3.00	0.00	6.12	0.00	4.92	0.00

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Table 20

Highway Mileage

From \ To	Abingdon	Bristol	Charlottesville	Danville	Farmville	Harrisonburg	Lexington	Lynchburg	Newport News	Norfolk	Portsmouth	Richmond	Roanoke	Staunton	Virginia Beach	Washington, D.C.	Williamsburg	Winchester	Wytheville
Abingdon	0	18	243	0	0	235	174	184	0	0	0	0	129	0	0	364	0	384	58
Bristol	18	0	261	0	0	253	192	202	0	0	0	0	147	0	0	382	0	322	76
Charlottesville	243	261	0	124	0	0	0	59	0	0	0	73	114	31	0	114	0	0	0
Danville	0	0	124	0	0	0	0	65	0	0	0	0	0	0	0	238	0	0	0
Farmville	0	0	0	0	0	0	0	53	0	0	0	72	102	0	0	0	0	0	0
Harrisonburg	235	253	0	0	0	0	61	0	0	0	0	0	106	27	0	129	0	69	177
Lexington	174	192	0	0	0	61	0	0	0	0	0	0	45	38	0	190	0	130	116
Lynchburg	184	202	59	65	53	0	0	0	0	0	0	120	55	0	0	173	0	0	0
Newport News	0	0	0	0	0	0	0	0	0	20	23	71	0	0	37	0	23	0	0
Norfolk	0	0	0	0	0	0	0	0	20	0	3	91	0	0	17	0	43	0	0
Portsmouth	0	0	0	0	0	0	0	0	23	3	0	94	0	0	20	0	46	0	0
Richmond	0	0	73	0	72	0	0	120	71	91	94	0	189	104	97	0	48	0	0
Roanoke	129	147	114	0	102	106	45	55	0	0	0	189	0	79	0	232	0	175	71
Staunton	0	0	31	0	0	27	38	0	0	0	0	104	79	0	0	155	0	95	150
Virginia Beach	0	0	0	0	0	0	0	0	37	17	20	97	0	0	0	0	59	0	0
Washington, D.C.	364	382	114	238	0	129	190	173	0	0	0	0	232	155	0	0	0	60	306
Williamsburg	0	0	0	0	0	0	0	0	23	43	46	48	0	0	59	0	0	0	0
Winchester	384	322	0	0	0	69	130	0	0	0	0	0	175	95	0	60	0	0	246
Wytheville	58	76	0	0	0	177	116	0	0	0	0	0	71	150	0	306	0	246	0

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NETWORK INVESTIGATION AND EVALUATION

This section describes the results of the estimates produced for travel on the Virginia bus network using three travel demand models (NECTP, Spaith and Michigan). The percentage of total intercity demand by bus is compared with trip length, bus fare, and frequency of service. Thus, the status quo is altered by increasing auto costs 50% and 100% and comparing the effects on bus patronage with bus fare increases of 10% and 20%. Finally, the frequency of service was increased by one and two departures per day.

Mode Split Model Performance

The mode split models utilized in the investigation are multinominal logit competition models whose variables are travel time, cost, and frequency of service. The forecasts produced by the mode split models were compared to each other and to the level of service parameters to gain an understanding of the market sensitivity.

General Results

The average bus market share forecasts of the CN26, Spaith, and Michigan mode split models are 5.59%, 13.19%, and 4.80% of the total market, respectively. A t-test was used to determine if the models produced significantly different mode split forecasts for a 0.05 level of confidence. The analysis indicated that the Spaith model produced significantly greater bus market share forecasts. The Michigan and CN26 mode split models produced forecasts that were statistically the same.

Market Share and Distance

Though distance does not explicitly enter any of the mode split models, it is a surrogate of travel time. Figures 20-22 present the bus market share estimations of the CN26, CN22, and Michigan mode split models in relation to the distance between origin and destination. Overall, the model estimations increase as trip length increases to 100 miles. For trips between 100 and 200 miles, the models estimate a constant market share of approximately 5% of the total market. For travel greater than 200 miles, the estimations do not show a clear pattern.

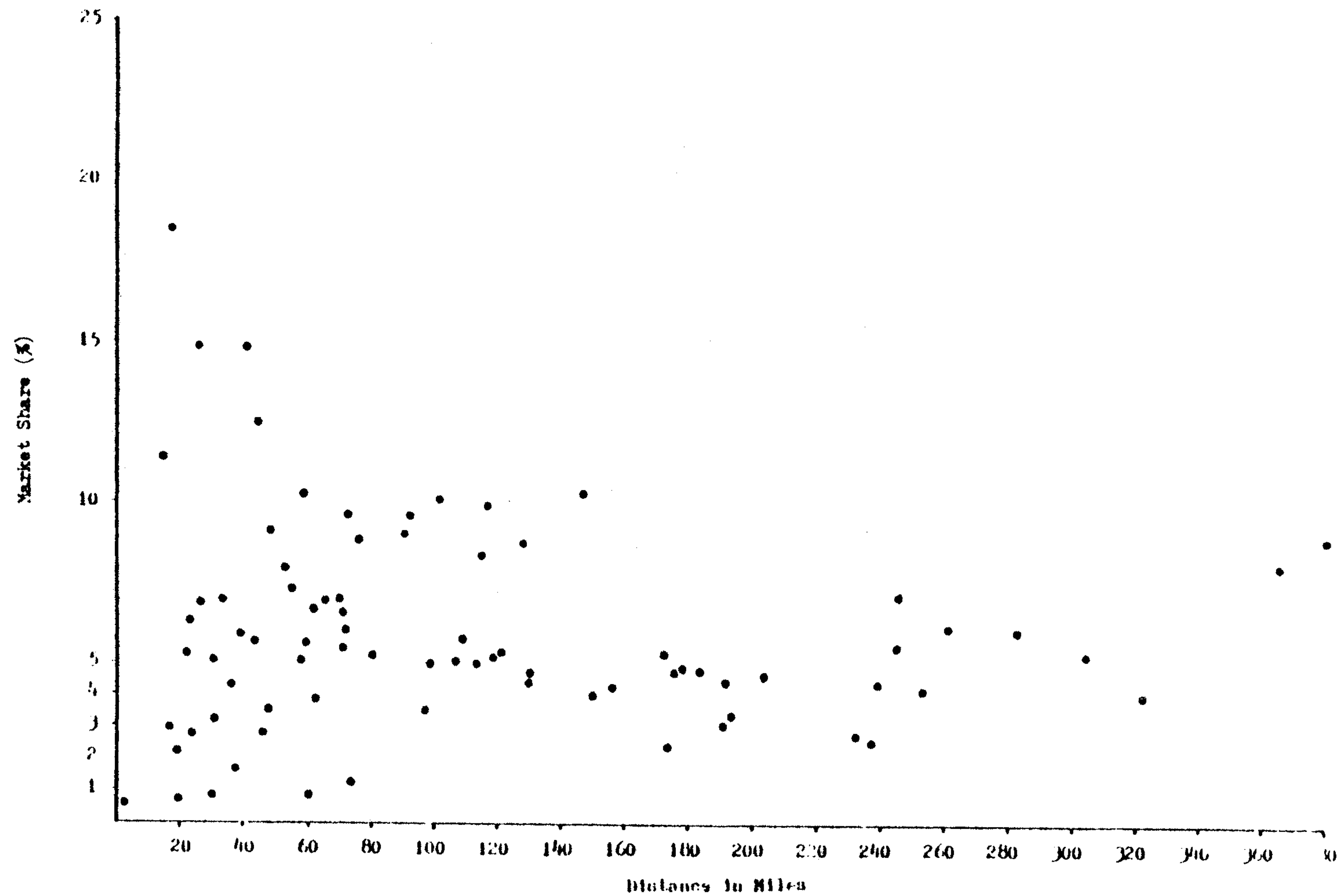

Figure 20. CN26 bus market share against distance.

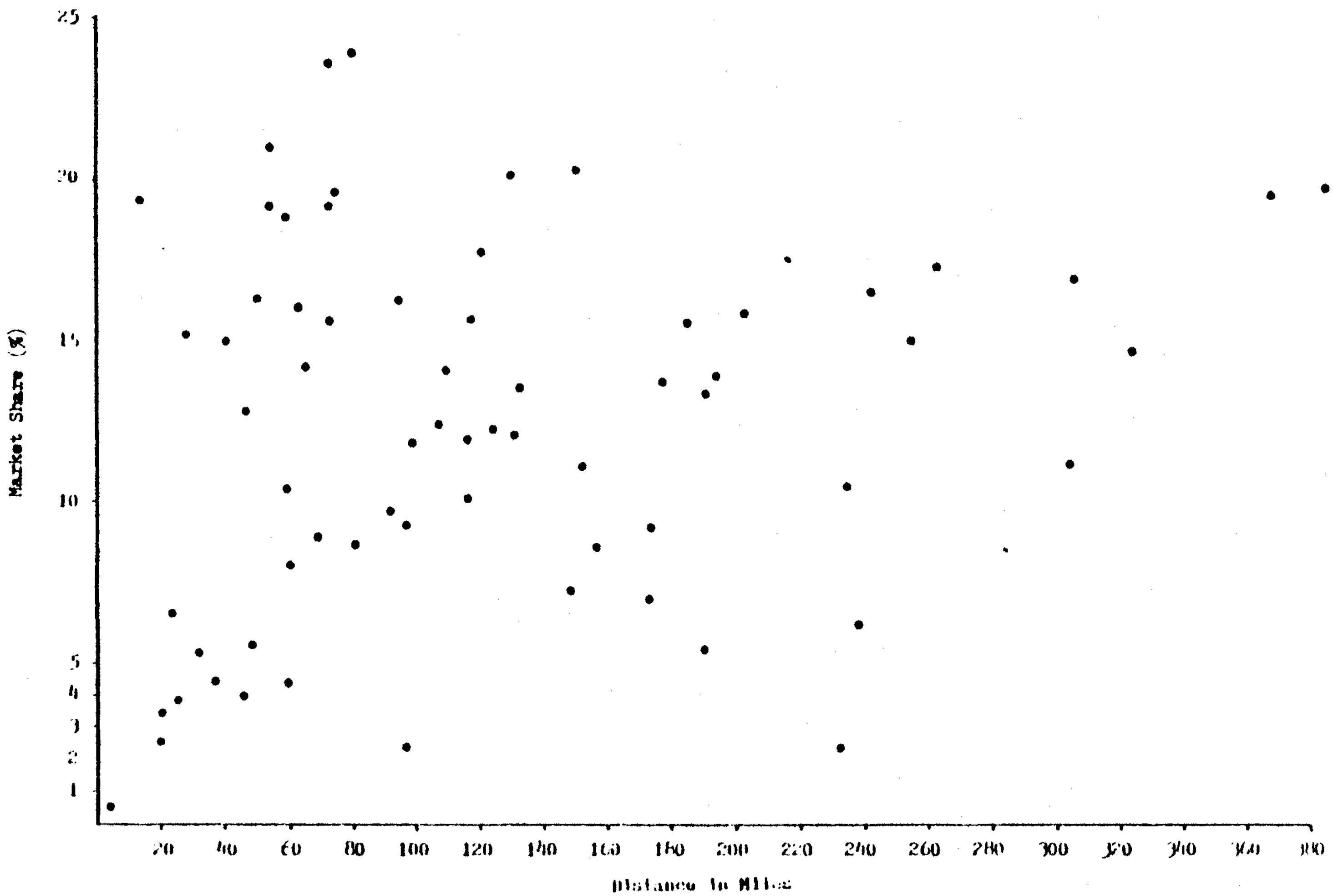

Figure 21. CN22 bus market share against distance.

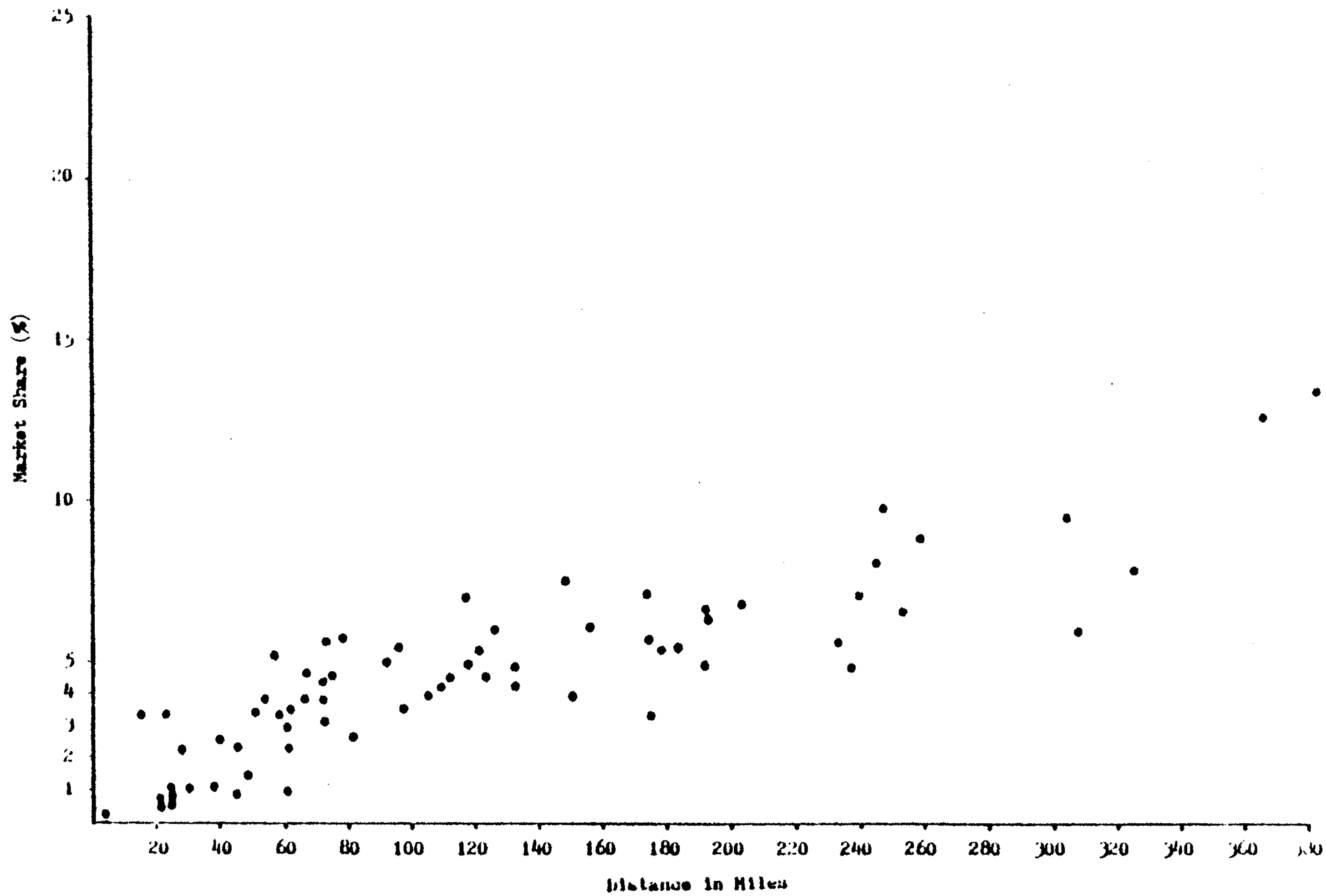

Figure 22. Michigan bus market share against distance.

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CN26 Mode Split Estimations

For travel less than 100 miles, the CN26 estimations cover a broad range of market shares, from 18% to less than 1% of the market, as shown in Figure 20. Even though there is a wide variation in the estimations, an increasing trend in the market share forecasts can be seen as trip length increases to 100 miles, where the bus market share is estimated at 5%. From 100 miles to 200 miles, the market share is maintained at 5%. Beyond 200 miles, the bus market share estimations do not indicate a reliable trend.

Spaith Mode Split Estimations

The CN22 mode split model is utilized in the Spaith travel demand model. The forecasts of the mode split model are presented in Figure 21. The results do not clearly define a trend in the bus market share estimations; however, some information on the bus market share can be obtained.

For trip lengths less than 100 miles, the estimations range from 2% to 24% of the travel market. The majority of the forecasts are above 8% and below 20% of the total market. For trip lengths between 100 and 200 miles, the estimations vary from a low of 6% to a high of 20%. The majority of the estimations fall between 10% and 17% of the total market. For trip lengths greater than 200 miles, a trend in the estimations is not defined.

Michigan Mode Split Estimations

The relationship between the bus market share and trip length is defined more definitively by the Michigan mode split model than by any other model tested, as shown in Figure 22. For trip lengths up to 100 miles, the bus market share increases to about 5% and then levels off until trip lengths exceed 200 miles. Beyond 200 miles, the trend is not clearly shown.

Bus Market Share and Bus Fare

The relationship between bus fare and bus market share is illustrated in Figures 23-25. For each mode split model, the bus market share increases as bus fares increase. The specific trend is for the bus market share to increase to 5% of the total market as bus fares increase to approximately $10. The bus market share is maintained at 5% as bus fares increase to $18. After a bus fare of $18, mode split trends are inconclusive. The following discussion examines the results of each mode split model.

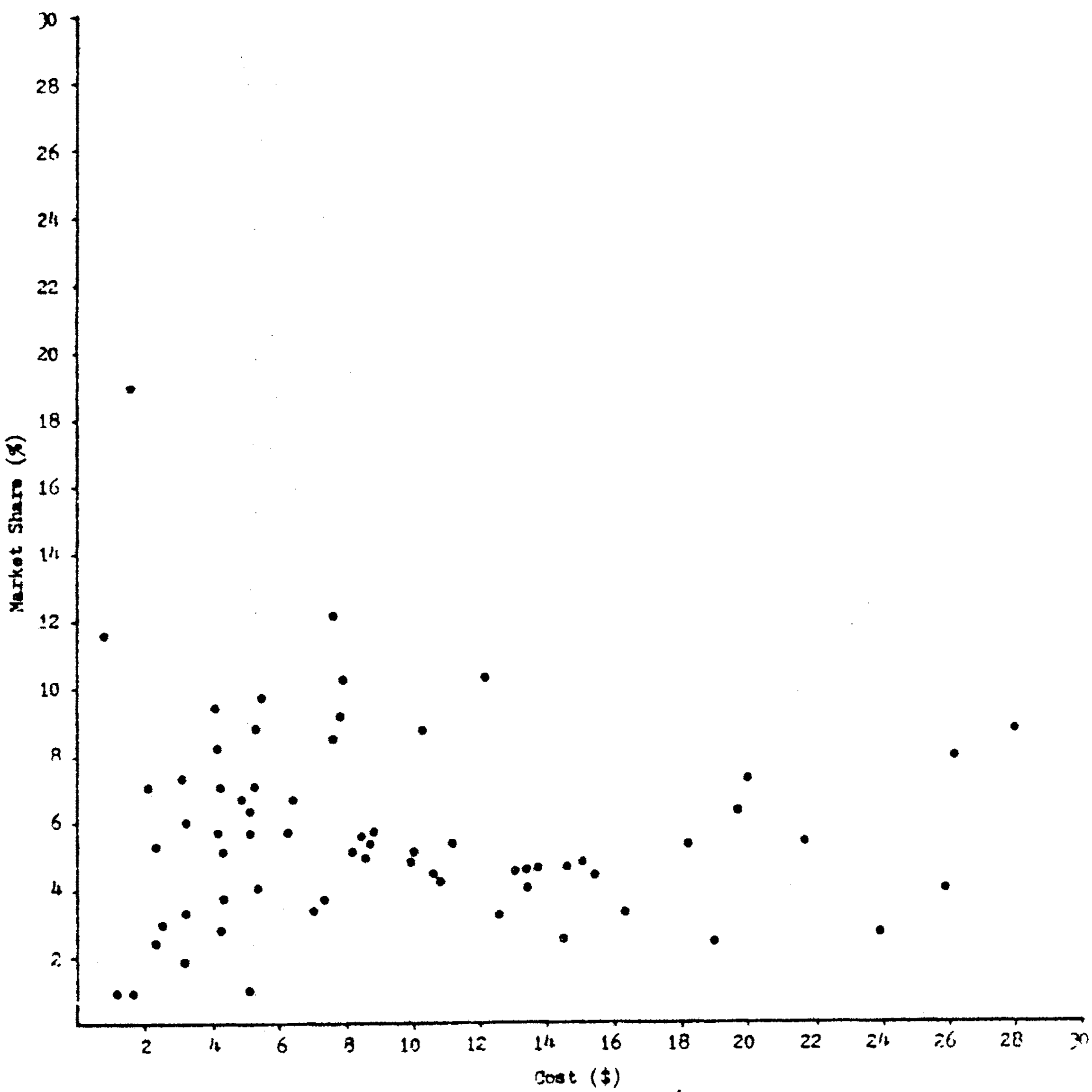

Figure 23. CN26 bus market share and bus fare.

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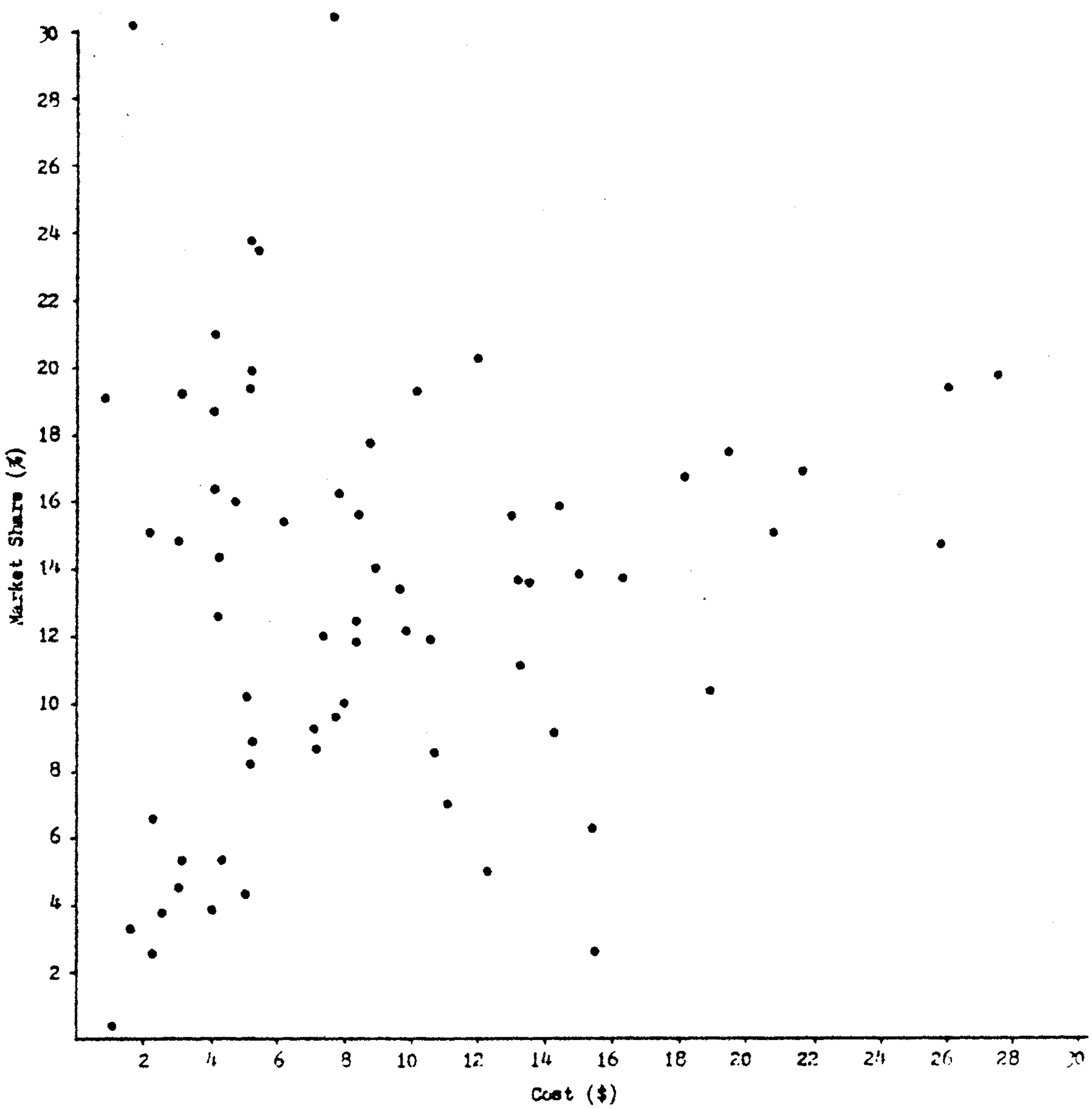

Figure 24. CN22 bus market share and bus fare.

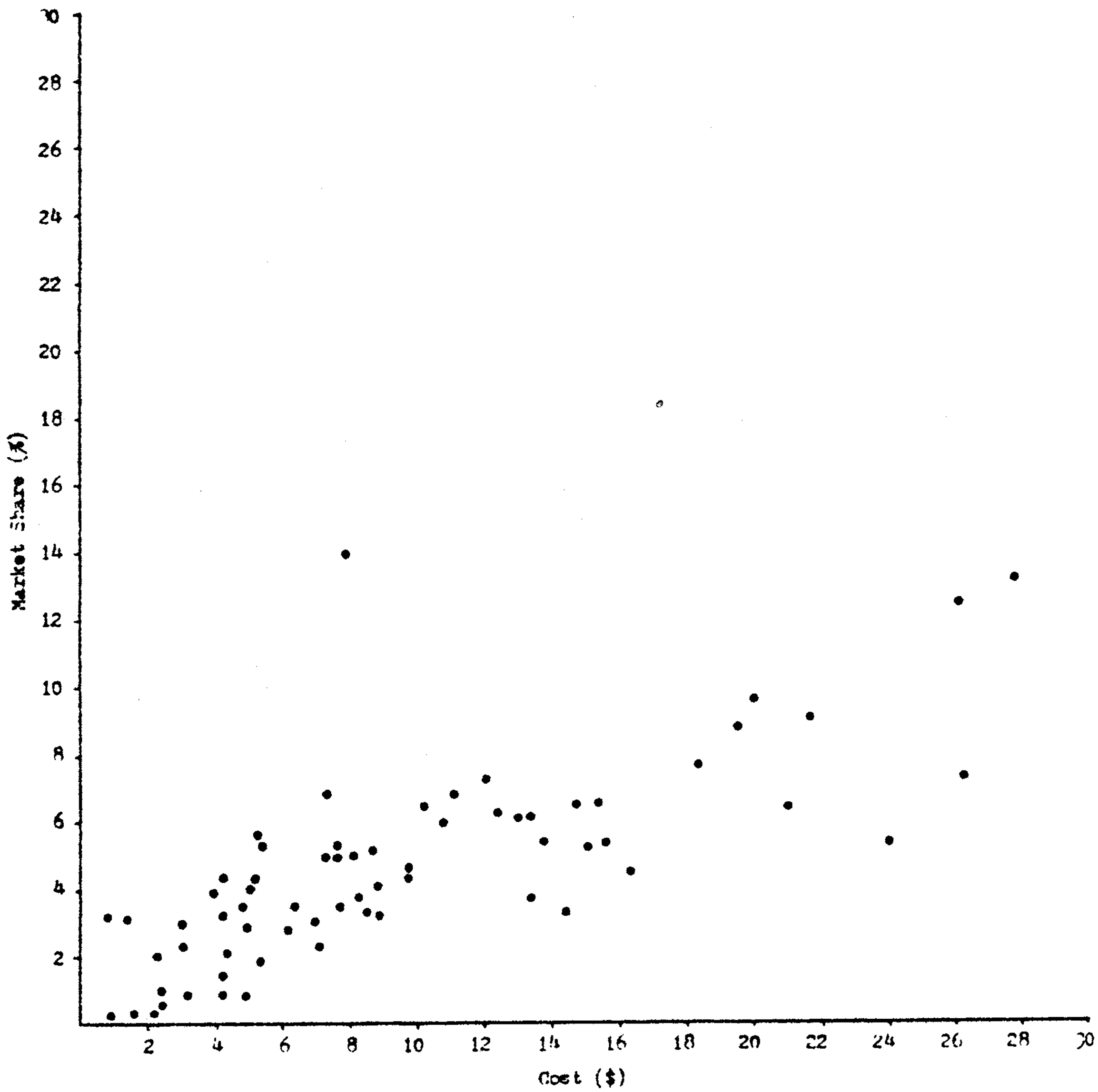

Figure 25. Michigan bus market share and bus fare.

CN26 Mode Split

The relationship of the CN26 bus market share to bus fare is shown in Figure 23. As bus fares increase to $6, the bus market share increases to approximately 5% of the total market. The bus market share levels off at this point until bus fares reach $18. Once bus fares exceed $18, the market share estimations do not lend themselves to a clearly defined trend.

Spaith Mode Split Estimations

The CN22 bus market share estimations are related to bus fares in Figure 24. The trend identified in the CN26 estimations is not as clearly illustrated in those for CN22. When the bus fare is below $10, there is a wide range of estimations ranging from a high of 24% with a bus fare of $6 to a low market share estimation of 2% for a bus fare of $2. As bus fares increase, the range of bus market share decreases to a high of 18% and a low of 10% of the total market.

Overall, there appears to be a decreasing upper bound and an increasing lower bound of the bus market share as bus fares increase. The upper limit is highest at 26% of the total market for a bus fare of $2, and lowest at 18% of the market for bus fares greater than $14. The lower bound is least at 2% of the market for a bus fare of $2 and highest at 14% of the market for bus fares greater than $18.

Michigan Mode Split Estimations

The relationship of the mode split estimations of the Michigan mode split model to bus fares is illustrated in Figure 25. The trend identified with the CN26 estimations is more clearly shown with the Michigan estimations. The bus market share increases from 2% to 5% of the market as fares increase to $10. For fares from $10 to $18, the bus market share is constant at approximately 5% of the market. The market share estimates for bus fares exceeding $18 show no clear trend.

Bus Market Share and Frequency

The relationship between frequency of bus service and market share is shown in Figures 26-28. For each mode split model the bus market share improves as the frequency of bus service increases from one to four departures per day. Improving the frequency of service beyond four departures per day does not improve the bus market share, which remains constant at approximately 5% of the total market.

CN26 Mode Split Estimations

The results of the CN26 mode split model are shown in relationship to frequency of service in Figure 26. As service is improved to five departures per day, the bus market share increases to approximately 6% of the market and maintains this market share for up to ten departures per day. Above ten departures per day, market share estimations do not show a definable trend.

Spaith Mode Split Estimations

The CN22 mode split estimations do not clearly define a trend as frequency of service increases (see Figure 27). Market share estimations are highest for two to five departures per day at approximately 14% of the market. Beyond five departures per day, the market share estimations vary over a broad range and disclose no trend.

Michigan Mode Split Estimation

The Michigan market share forecasts illustrate the same trend as the CN26 mode split estimations as shown in Figure 28. For one to four departures per day, the bus market share increases from 1% to 5% of the total market. For five or more departures per day, the bus market share remains constant at 5% of the market until ten departures per day. The market share estimations are inconclusive for more than ten departures per day.

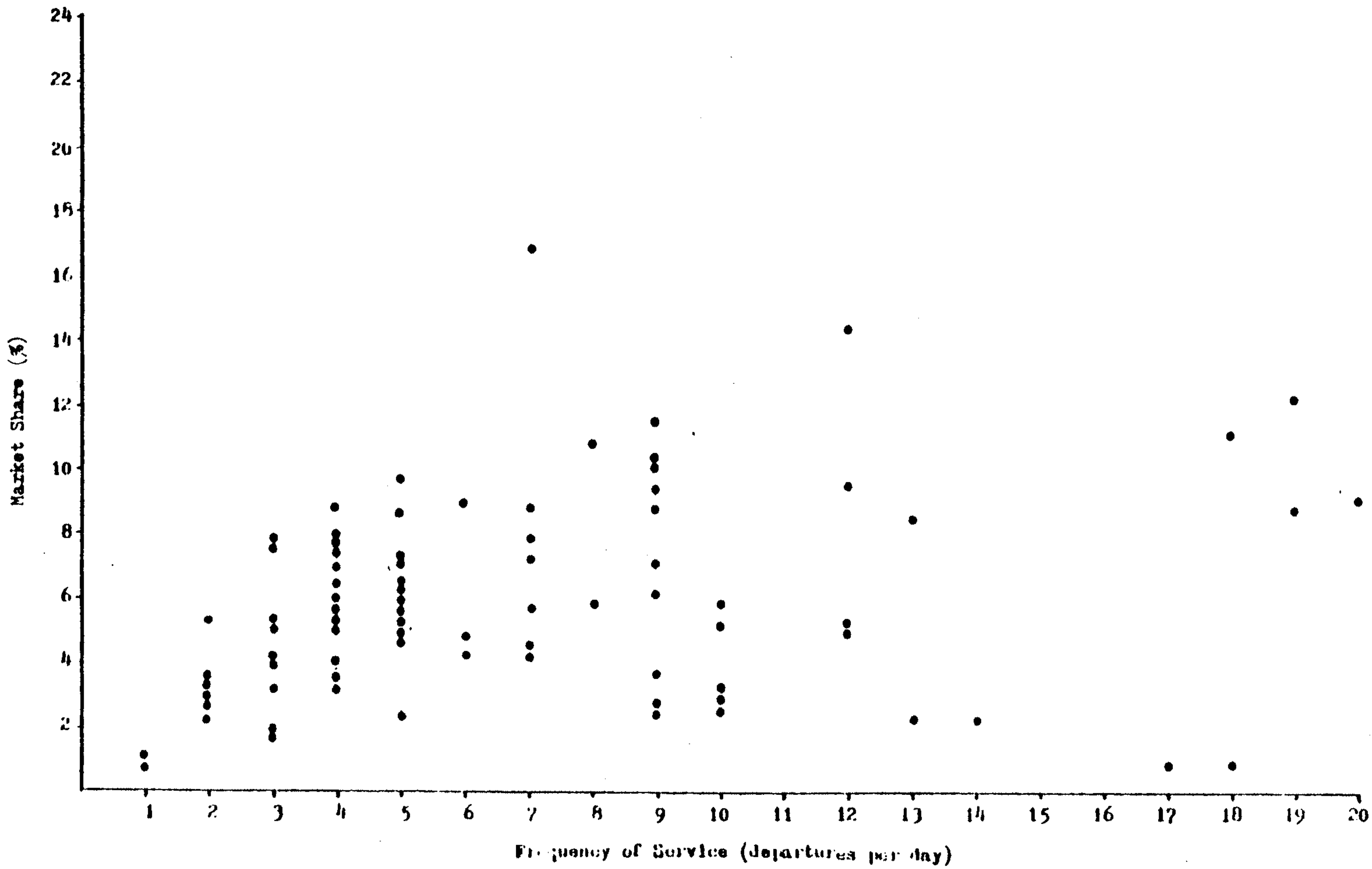

Figure 26. CN26 bus market share against bus frequency.

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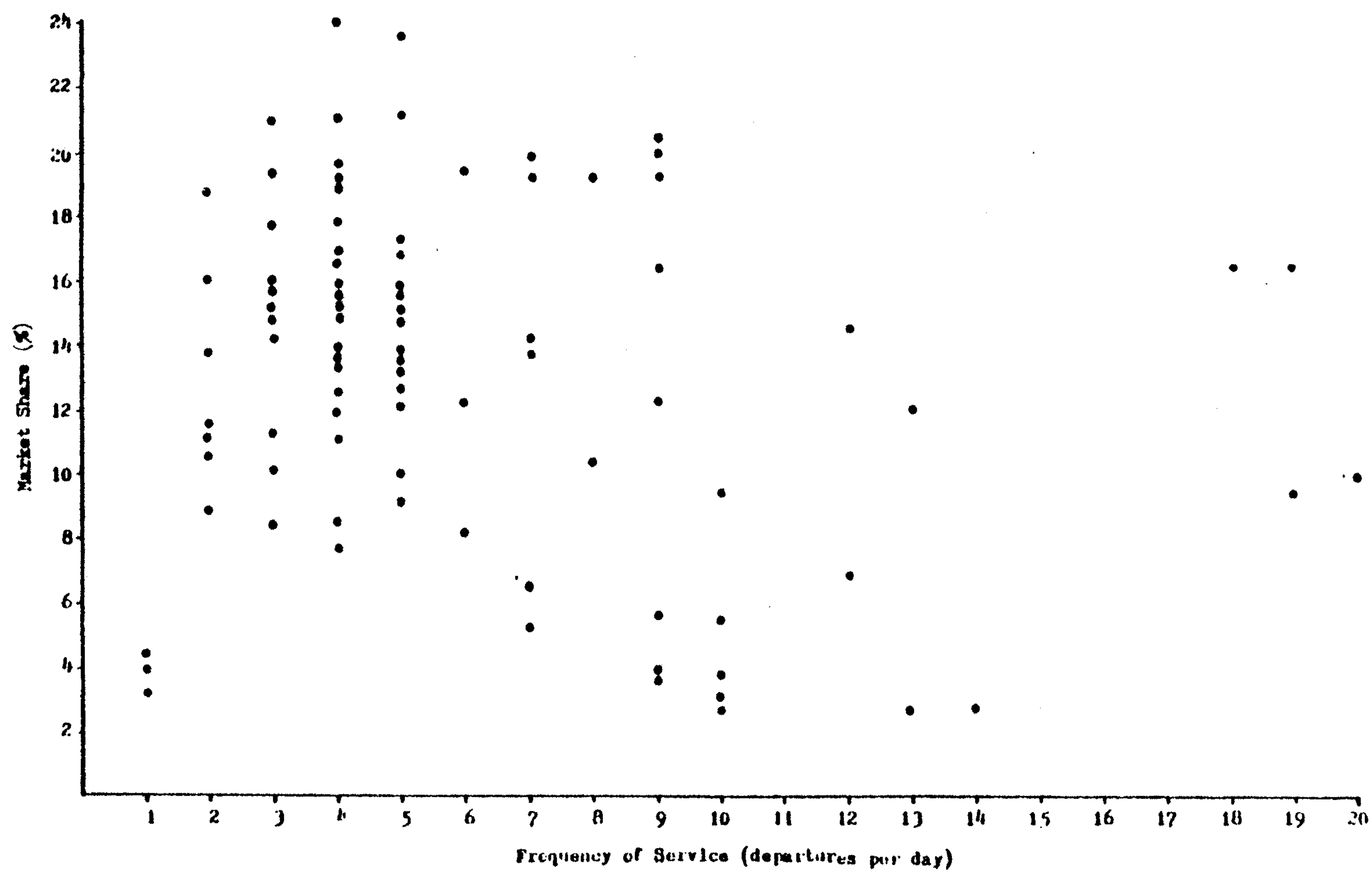

Figure 27. CN22 bus market share against bus frequency.

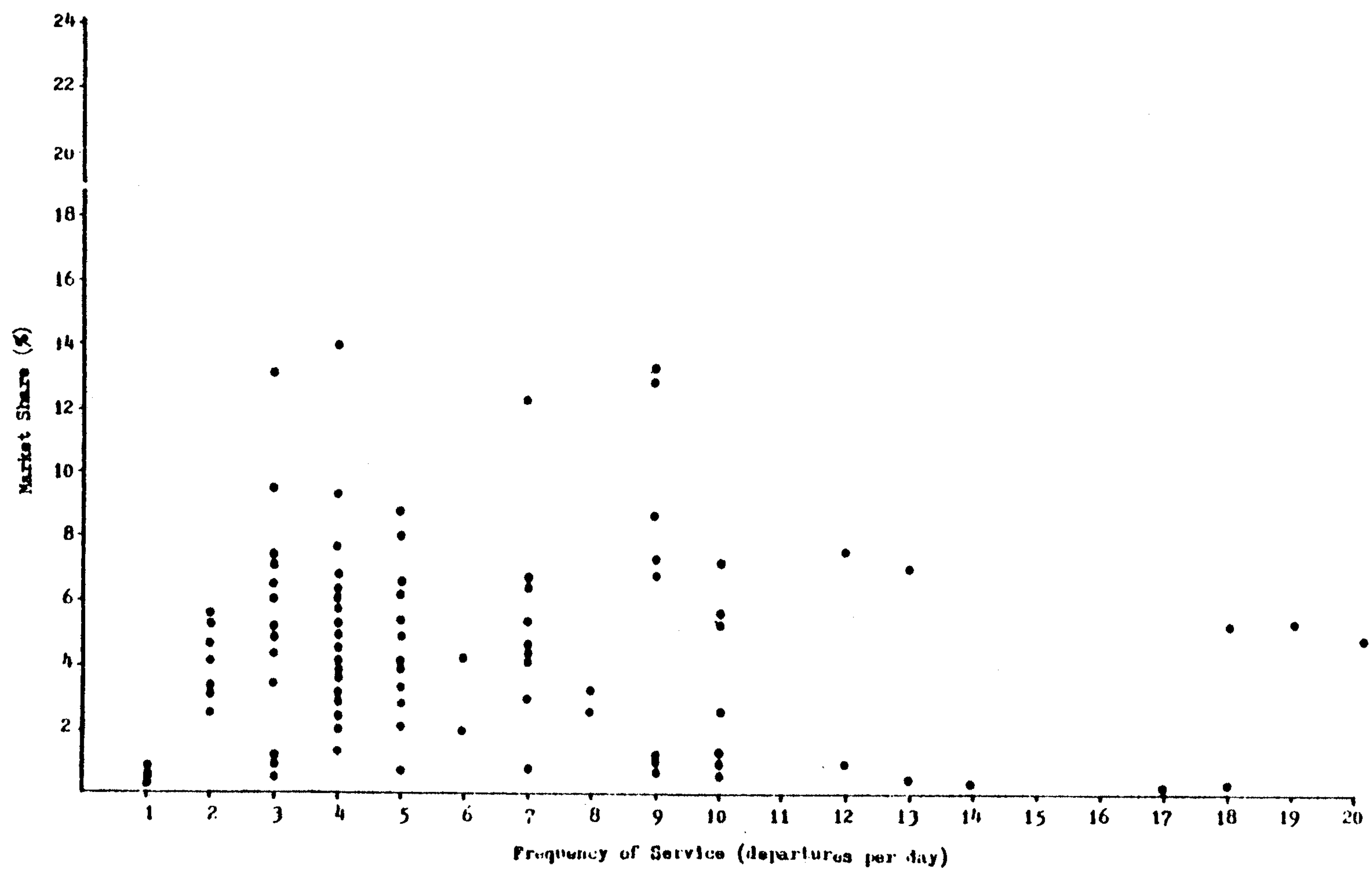

Figure 28. Michigan bus market share against bus frequency.

Conclusions

The results produced by the three mode split models indicate that the bus market share remains constant over a range of the level of service parameters. There appears to be a range over which the bus market share can be improved by increasing the level of service, but increasing the level of service beyond a point yields inconclusive estimations of the bus market share.

The bus market share remains approximately constant at 5% of the total market for the following ranges in value of the level of service parameters: travel distance — 100 to 200 miles, fare — $10 to $18, and frequency — 4 to 10 departures a day. Below these values, increasing the level of service results in increased estimations of the bus market share. Beyond these values, the effect of increasing the level of service on the bus market share is not established.

The CN26 and Michigan mode split models produce statistically equal bus market share estimations and define the clearest trends as the level of service varies from link to link. The forecasts are within a reasonable range. The intercity bus market share never exceeds 10%. The Spaith mode split model forecasts bus market shares considerably in excess of those by the CN26 and Michigan mode split models and apparently unreasonable for existing market conditions.

Level of Service Scenarios

The purpose of this portion of the network investigation was to gain insight into bus market sensitivity as it pertains to various policy alternatives. The technique employed was to examine the bus market share forecasts for changes in the frequency of service and relative cost and compare these to present conditions.

Frequency of Service Scenario

Increasing the frequency of bus service by one or two departures per day had a minimal impact on the bus market share. For example, as shown in Table 21, the bus market share increased from 4.8% to 5.2% if there were two additional bus departures.

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Table 21

Frequency of Service Scenario

Bus Market Share

	CN26			Spaith			Michigan		
	F	F+1	F+2	F	F+1	F+2	F	F+1	F+2
$\overline{X}$	.0559	.0618	.0662	.1319	.1327	.1333	.0480	.0502	.0520
s	.0296	.0304	.0320	.0639	.0642	.0645	.0282	.0292	.0301
n	69	69	69	69	69	69	65	65	65

F=existing bus frequency of service (departures per day)

Cost Scenario - Increased Auto Costs

The increased auto cost case of the cost scenario increased the cost of traveling by automobile by 50% and 100%. The purpose of this scenario case was to eliminate inaccuracies produced by the DOT automobile cost formula and to reflect the increasing cost of fuel.

Table 22 presents the average bus market shares of the mode split models and their associated standard deviations. A t-test indicates that for a 95% level of confidence, there is a significant increase in the bus market share as automobile costs increase by 50% and 100%.

Table 22

Cost Scenario: Auto Case

Bus Market Share

	CN26			Spaith			Michigan		
	C	C*1.50	C*2.0	C	C*1.50	C*2.0	C	C*1.50	C*2.0
$\overline{X}$	.0559	.0753	.0925	.1319	.1887	.2370	.0480	.0902	.1366
s	.0296	.1394	.1479	.0639	.0906	.1124	.0282	.0508	.0704
n	69	69	69	69	69	69	65	65	65

c=existing auto costs ($)

Cost Scenario - Increase Auto and Common Carrier Costs

The increased auto and common carrier costs case of the cost scenario involved increasing the automobile costs by 50% and increasing all common carrier costs by 10% and 20%. The premise underlying this scenario is that the automobile costs will increase prior to increases in common carrier fares. The case was intended to identify how much increasing common carrier fares would erode the gains made by the bus market when only the automobile costs were increased.

Table 23 presents the results of the scenario. A t-test indicates that if bus fares increased by 10% after automobile costs had increased by 50%, there would be no significant decrease in the bus market share for a 95% level of confidence. An increase in bus fares of 20% following a 50% increase in automobile costs would result in a significant decrease in the bus market share. However, the bus market share for such a condition would be significantly greater than the bus market share forecast for existing conditions at a 95% level of confidence.

Table 23

Cost Scenario: Common Carrier Case

Bus Market Share

	CN26			Spaith			Michigan		
	C_a*1.50	C*1.10	C*1.20	C_a*1.50	C*1.10	C*1.20	C_a1.50	C*1.10	C*1.20
$\bar{X}$	.0753	.0703	.0660	.1887	.1742	.1621	.0902	.0788	.0686
s	.0394	.0369	.0347	.0906	.0839	.0783	.0508	.0451	.0404
n	69	69	69	69	69	69	65	65	65

C_a=existing auto cost ($)
C =existing bus fare ($)

Summary of Results

The network investigation revealed information on market sensitivity as it pertains to trip length, travel cost, and frequency of service. The level of service scenarios utilized in the investigation were a status quo scenario, frequency of service scenario and a cost scenario.

The status quo scenario produced information on the dynamics of the bus market share as influenced by trip length, cost, and frequency of service. In general, the findings showed a range of trip lengths, cost, and frequencies over which the bus market share remained constant at 5% of the travel market. The bus market share remained constant for:

1. trip lengths between 100 miles and 200 miles,

2. bus fares between $10 and $18, and

3. frequency of bus service between 4 and 10 departures per day.

Below these ranges increases in trip length, fare, and frequency of service improved the bus market share. Above these ranges, the mode split models produced inconclusive trends.

The level of service scenarios provided insight into the sensitivity of the bus market. The frequency of service scenario indicated that the bus market share is insensitive to the frequency of bus service. A unit increase in bus departures per day resulted in an approximate 0.5% increase in the bus market share.

The cost scenario showed that increasing automobile costs resulted in significant improvements in the bus market share. A 50% increase in automobile costs resulted in an average 3.8% increase in the bus market share. Raising common carrier fares while also increasing automobile costs showed that a 10% increase in fares will not significantly erode the gain in the bus market share which resulted from a 50% increase in automobile costs.

The two level of service scenarios indicated that the bus market share as estimated by the mode split models is insensitive to the frequency of bus service and is sensitive to automobile costs. Furthermore, the results of the cost scenario showed that increases in the bus fare should remain below increases in automobile costs to increase the bus market share.

In an overall sense, the Michigan mode split model provided the most concise information and is, therefore, the best mode split model. The next best model is the CN26 mode split model. Both the Michigan and CN26 models produced information which appeared to be reasonable. The CN22 mode split model provided wide ranges in forecasts which were well above the market shares found by the state of New York. However, this does not mean that the results from any of the mode split models accurately reflect the true characteristics of the Virginia intercity bus market, because all the models have calibrations from other parts of the country.

CONCLUSIONS AND RECOMMENDATIONS

The investigation of intercity bus transportation based on the Virginia network has produced the following conclusions and recommendations.

Conclusions

Conclusion No. 1

The intercity bus market is insensitive to the frequency of bus service. The increasing market share trend indicated by the status quo scenario for 1-4 departures per day is deceptive. Of the 138 city pairs, 31 (22.5%) are served by less than 4 buses per day. An examination of the data indicates that 30 of the 31 city pairs have populations of less than 10,000 persons. It appears that the bus operators have determined through experience that these city pairs cannot support additional service. All of the 31 city pairs could have additional service, since buses do pass through them without stopping.

Conclusion No. 2

The bus market share is sensitive to escalating travel costs. As gasoline prices rise, the intercity bus market share will increase provided that bus fares increase at a rate less than the rate at which automobile travel costs escalate. Both the status quo and cost scenarios indicate that as travel costs increase, the bus market share increases.

It appears that as travel costs increase, the bus industry's fare structure improves the attractiveness of traveling by intercity bus. Travel costs are a crude measure of trip length since as trip lengths increase, travel costs increase. Bus fares appear to be structured such that as the differential between automobile travel costs and bus fares increases, the inconvenience of traveling by bus is perceived to be alleviated. The increased savings outweigh the increase in travel time required in traveling by bus.

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Conclusion No. 3

The accuracy of the forecasts is indeterminable since Virginia ridership data were unobtainable. However, of the three mode split models, the calibration utilized by the Michigan model produced the most consistent estimations. The CN26 calibration of the NECTP model provided the next best results, producing forecasts similar to those produced by the Michigan model. The CN22 calibration of the NECTP model resulted in erratic estimations which did not identify trends in the bus market share. The CN26 and Michigan models rarely produced bus market share estimations greater than 10%, which is reasonable. The CN22 model regularly produced bus market shares in excess of 30%.

Overall, when applied to the Virginia conditions, the segmented approach of the Michigan model appears to be better than the approach taken by William Spaith in his model.

Recommendations

The lack of a comparative data base makes specific recommendations difficult. The results and conclusions of the project provide some implications for bus operators and the Commonwealth.

Implications for Bus Operators

Bus fares should increase at a rate less than the rate at which automobile costs escalate for buses to gain an increasing share of the travel market. Such a policy will increase ridership more for long distance trips than for short distance trips. However, the gains for short trips will also be significant. A fare policy which increases the cost differential between the automobile and intercity bus will improve the bus market share.

The finding that the bus market share is insensitive to the frequency of bus service does not indicate that new buses should not be purchased. While purchasing new buses to improve the frequency of service will have only a modest impact on ridership, the replacement of older equipment is necessary.

Implications for the State

The data collection task of the project indicated that the intercity bus is a vital service to many of the small towns of Virginia. Research should be undertaken to maintain and improve the level of intercity transportation service.

Since the bus market share was shown to be sensitive to travel costs, policies affecting the bus industry should reflect this sensitivity. State policies should allow for a changing cost environment as fuel costs increase dramatically.

Recommendations for Future Research

Three recommendations for further research are discussed. The first recommendation would result in information on transportation patterns in Virginia. The second recommendation concentrates on intercity transportation alternatives to the automobile and how those alternatives have been changing through time. The third recommendation is concerned with developing additional information about the Virginia intercity bus industry and its users.

Research Recommendation No. 1

The data collection task of the research identified an area where further research would be beneficial. General intercity travel patterns within Virginia have not been clearly defined. The clarification of production and attraction travel sources would provide information on the hinterlands of the major population centers within Virginia. Travel characteristics, including trip origin and destination, could be utilized to plan both private and public, regional and interregional transportation service.

Three sources could supply a measure of intercity travel within Virginia. They are a road side survey, telephone calls, and the volume of mail. Road side surveys throughout the state would be expensive to conduct. Therefore, a road side survey could be utilized to collect a small travel pattern data base to calibrate a transferred travel demand model.

The number of telephone calls between two cities and the volume of mail are surrogates to travel, since transportation is the means to face-to-face communications. Telephone calls and mail are means of other forms of communications. Spot highway counts could be used to adjust the parameter. Spot counts including highway vehicle mix could supply sufficient data on mode split.

Research Recommendation No. 2

To gain additional insight into the Virginia intercity bus industry, its historical trends should be identified. National bus trends indicate that intercity bus service has been deteriorating for the past decade. The degree of decline of Virginia intercity bus operations is unknown. By identifying the degree of decline, the stability of the bus industry and the stability of public transportation service to small towns and communities in Virginia would be known. Such an investigation would point out which communities have inadequate intercity travel alternatives to the private automobile.

Two approaches can be taken to produce data on Virginia intercity bus trends. Contacts with the bus operators can produce level of service data for past years, including schedules and tariffs. However, ridership data are unavailable. Financial trends could be found through the State Corporation Commission.

Research Recommendation No. 3

The third recommendation for further research concentrates on the Virginia intercity bus industry. An on-board bus user survey would provide information on a wide range of factors. Ridership levels would be found and these could be used in the identification of parameters and their impact on ridership through a regression and correlation analysis. Ridership levels could also be used to calibrate transferred travel demand models.

An on-board bus user survey would also provide a profile of a typical Virginia intercity bus user. Once the user is clearly defined, policies could be identified and implemented to meet the needs of the bus user.

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